

(19) World Intellectual Property Organization  
International Bureau



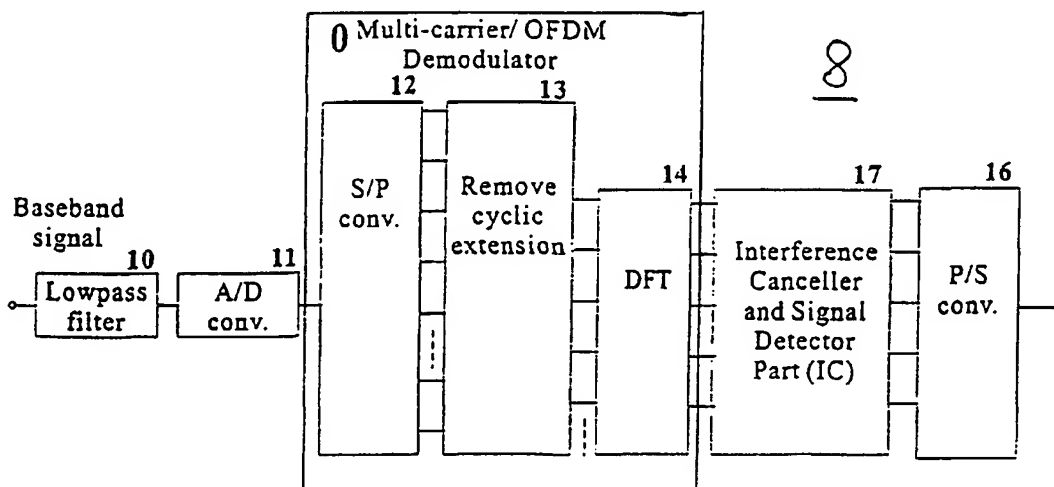
(43) International Publication Date  
7 June 2001 (07.06.2001)

PCT

(10) International Publication Number  
**WO 01/41387 A1**

- (51) International Patent Classification<sup>7</sup>: **H04L 27/26**, 25/03, H04B 7/08, H04L 1/06
- (21) International Application Number: PCT/EP99/09239
- (22) International Filing Date:  
27 November 1999 (27.11.1999)
- (25) Filing Language: English
- (26) Publication Language: English
- (71) Applicant (*for all designated States except US*):  
**DEUTSCHE TELEKOM AG** [DE/DE]; Friedrich-Ebert-Allee 140, D-53113 Bonn (DE).
- (72) Inventors; and
- (75) Inventors/Applicants (*for US only*): **CZYLWIK, Andreas** [DE/DE]; Kirchstr. 41, D-68647 Biblis (DE). **YOSHINO, Hitoshi** [JP/JP]; NTT Mobile Communications Network Inc., Wireless Laboratories, 3-5 Hikari-no-oka, Yokosuka, Ranagan 239-8536 (JP).
- (74) Agent: **KAMPFENKEL, Klaus**; Blumbach, Kramer & Partner GbR, Alexandrastrasse 5, D-65187 Wiesbaden (DE).
- (81) Designated States (*national*): AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
- Published:  
— With international search report.
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: METHOD FOR CO-CHANNEL INTERFERENCE CANCELLATION IN A MULTICARRIER COMMUNICATION SYSTEM



(57) Abstract: The present invention relates to an interference signal canceling method, a receiver using the same and a digital multi-carrier communication system comprising such a receiver. A main aspect of the present invention is to apply an interference cancellation scheme to a digital multi-carrier communication system. By using a digital multi-carrier communication system, the effect of the inter-symbol interference is avoided. As a result the receiver (8) comprises a plurality (L) of interference cancellers (17<sub>1</sub>-17<sub>L</sub>) each of which is associated to a respective one of sub-carrier signals for canceling only co-channel interference.

## METHOD FOR CO-CHANNEL INTERFERENCE CANCELATION IN A MULTICARRIER COMMUNICATION SYSTEM

The present invention relates to an interference signal  
canceling method, a receiver using the same and a digital  
multi-carrier communication system comprising such a  
receiver. More particularly, it relates to an interference  
signal canceling method which compensates the transmission  
performance degradation due to co-channel or similar  
interference signals from other adjacent cells in digital  
mobile radio communication or other adjacent transmitter in  
digital wireless communication or in digital broadcasting  
system and a receiver and a communication system using such  
an interference signal canceling method.

There have already been proposed several types of  
receivers which employ replica generators for interference  
canceling. They generate replicas by using transmission  
symbol candidates both for desired and interference signals,  
and transmission channel parameters corresponding to these  
two signals. Then, they subtract these replicas from a  
received signal to obtain an error signal. They multiply the  
square of the error signal by -1 and use the resulting signal  
as a metric for a maximum likelihood sequence estimation  
(MLSE) both for desired and inter-channel interference  
signals under inter-symbol interference condition.

For example, W. Van Etten has proposed a receiver using  
the Viterbi algorithm as a maximum likelihood sequence  
estimator (W. Van Etten, "Maximum Likelihood Receiver for  
Multiple Channel Transmission System," IEEE Trans. on Comm.

February 1976). However, this receiver is based on the assumption that the channel impulse response values are preknown. A receiver that estimates channel parameters and employs a maximum likelihood sequence estimation has been  
5 proposed by Howard E. Nicols, Arithur A. Giordano and John G. Proakis (H. E. Nichols, A. A. Giordano, and J. G. Proakis, "MLD and MSE algorithm for adaptive detection of digital signals in the presence of interchannel interference," IEEE Trans. on Information Theory, September 1977). According to  
10 their proposal, the channel parameters are estimated and updated by an adaptation algorithm by using an estimated symbol value which is output from the maximum likelihood sequence estimator with a decision delay of several symbol duration. This receiver operates well when the radio channel  
15 has relatively slow time-variations. In the mobile radio channel, however, since the amplitudes and phases of desired and interference signals vary very rapidly, the estimated channel parameters with the time delay of several symbol duration represent no longer the current channel impulse  
20 response. Hence, the transmission performance is seriously degraded.

To improve the transmission performance of a receiver based on the maximum likelihood sequence estimation scheme, A.P. Clark, J. D. Harvey and J. P. Driscoll have proposed a  
25 Near-Maximum-Likelihood detection scheme as a solution to the poor channel parameter estimation due to the fixed estimation delay which poses a serious problem in the adaptive maximum likelihood sequence estimation receiver (A. P. Clark, J. D. Harvey and J. P. Driscoll, "Near-Maximum-Likelihood detection  
30 processes for distorted digital signals, "Radio & Electronics Engineer, Vol. 48, No. 6, pp.301-309, June 1978).

Moreover, A. P. Clark has proposed an FDM (Frequency Division Multiplexing) system that transmits two signals over the same frequency channel through utilization of the Near-Maximum-Likelihood detection scheme (U.S. Pat. No. 4,862,483).

5 In this system, however, the number of the transmission signal sequence candidates (first vector) to be stored in a memory and the number of the sets of transmission channel parameters (vectors) corresponding to the first vector are large. Each first vector is extended into a second vector by  
10 adding a further component representing a respective combination of data symbols that could be received at the sample instant. New signal sequence candidates (first vectors) are selected among the extended signal sequence candidates (i.e. second vectors) in a highest likelihood  
15 order. When the likelihood of the transmission signal sequence candidate (first vector) who has the highest likelihood is extremely higher than that of the other signal sequence candidates (first vectors), the likelihood order of the extended sequence candidates (second vectors) depends  
20 dominantly on the likelihood value of the first vector. Hence, there is almost no possibility of other first vectors being selected. This receiver can no longer be considered as a maximum likelihood detector.

H. Yoshino, K. Fukawa and H. Suzuki have proposed, as an  
25 interference signal canceling method, a receiver using a transmission parameter estimation scheme suitable for the maximum likelihood sequence estimation which keeps high-speed, precise track of the fast fading or fast changing mobile radio channel (U.S. Pat. No. 5,537,443). An  
30 interference canceller of this scheme cancels both inter-symbol interference and co-channel interference, but the number of the states in the Viterbi algorithm increases

exponentially as the maximum excess delay caused by multi-path propagation increases. When the signal delay exceeds the maximum signal delay considered in the Viterbi algorithm, the maximum likelihood sequence estimator does not work, and the transmission performance is seriously degraded.

On the other hand, S. B. Weinstein and P. M. Ebert have proposed a modulation and demodulation scheme to overcome the effect of the inter-symbol interference which is denoted orthogonal frequency division multiplexing (OFDM) and uses the discrete Fourier transform (S. B. Weinstein and P. M. Ebert, "Data transmission by frequency division multiplexing using the discrete Fourier transform," IEEE Trans. on Comm., October 1971). A receiver of this scheme does not cancel co-channel interference, and hence possesses the drawback that it does not operate in a high co-channel interference environment.

The present invention applies the above mentioned transmission channel parameter estimation scheme and co-channel interference cancellation scheme to an above mentioned frequency division multiplexing system. By using frequency division multiplexing system, the effect of the inter-symbol interference is avoided. By exploiting the different channel characteristics, say, the difference in amplitudes and phases between desired and interference signals, the transmitted symbol sequences can be simultaneously estimated both for the desired and the interference signals).

A description will be given first, with reference to FIG.1A and FIG.1B, of a conventional scheme of the orthogonal frequency division multiplexing (OFDM) data transmission that has the above-said feature of avoiding the intersymbol interference. Fig. 1A shows the transmitter scheme for an

OFDM data transmission system. This transmitter is made up of: a serial to parallel (S/P) converter 1 which converts serial data stream to a set of  $L$  parallel data streams; parallel baseband modulators 2 to which the data in each sub-channel are fed; an inverse discrete Fourier transform (IDFT) device 3, whose outputs correspond to  $L$  channel transmitted signals with carrier frequencies  $f_0, f_1, \dots, f_{L-1}$ , where the frequency difference between adjacent channels is  $Df$  and the overall bandwidth  $W$  of the  $L$  modulated carriers is  $L Df$ ; a cyclic extension device 4 which adds a cyclic prefix (guard interval) in order to avoid the effect caused by inter-block interference; a parallel to serial converter (P/S) 5 to output time domain signal; a digital-to-analog (D/A) converter 6 which converts digital signal to an analog waveform; and a low pass filter 7 which limits the frequency spectrum.

Fig. 1B shows the receiver scheme for an OFDM data transmission system. This receiver is made up of a low pass filter 10 which band-limits the received signal; an analog-to-digital (A/D) converter 11 which converts the analog received signal to digital form; a serial-to-parallel (S/P) converter 12 which converts the serial received signal to  $L$  parallel data streams; a remove cyclic extension device 13 which removes the cyclic prefix in order to remove the effect of time domain inter-symbol interference; a discrete Fourier transform (DFT) device 14 whose output are  $L$  sub-carrier channels;  $L$  baseband demodulators 15 which demodulate baseband received symbols to digital data bits; and a parallel-to-serial (P/S) converter 16 which recombines digital data bits to a serial data bit sequence. An advantage of the OFDM data transmission system is that OFDM reduces the effects of intersymbol interference (ISI) by lowering the

symbol rate for each sub-carrier. Particularly, for the application of high bit rate digital signal transmission, OFDM also can eliminate the effect of ISI by adding a cyclic prefix, the length of which is set to be greater than the maximum excess delay of the transmission channel. When the received signal contains an interference signal from another transmitter, the interference signal still remains on each of the sub-channels so that the transmission performance is seriously degraded. In a cellular mobile communication system in which each cell may sometimes receive a co-channel interference signal from an adjacent cell, or in wireless local or wide area network in which the same frequency channel is reused (e.g. space division multiple access (SDMA) systems), there is a strong demand for canceling the influence of the interference. In a digital broadcasting system, such as digital audio broadcasting (DAB) or digital video broadcasting (DVB), the receiver at the fringe of a broadcasting service area suffers a co-channel interference from the transmitter in an adjacent broadcasting service area if in both service areas the same frequency channels are used. Thus, there is also a strong demand for canceling the interference signal.

An object of the present invention is to provide a multi-carrier receiver, e. g. an OFDM receiver, a digital signal transmission multi-carrier communication system and a method for canceling co-channel interference in a multi-carrier signal which use a less complex and thus a cheaper interference cancellation scheme than the prior art according to US-PS-5 537 443.

A main aspect of the present invention is to apply the above mentioned interference cancellation scheme to a digital multi-carrier communication system. By using a digital multi-

carrier communication system, the effect of the inter-symbol interference is avoided. As a result an interference canceller which only cancels co-channel interference is used for each sub-carrier signal. By exploiting the different  
5 channel characteristics, say, the difference in amplitudes and phases between desired and interference signals, the transmitted symbol sequences can be simultaneously estimated both for the desired and the interference signals.

The above mentioned technical problem is solved by the  
10 features of claim 1, claim 18 and claim 19, respectively.

Further preferred embodiments are set forth in the dependent claims.

The receiver comprises at least one receiving branch, wherein each receiving branch comprises demodulating means  
15 for converting a received serial multi-carrier signal including at least one desired and interference signal into a plurality of sub-carrier signals, and a plurality of interference cancellers each of which is associated to a respective one of said sub-carrier signals for canceling co-  
20 channel interference.

In a preferred embodiment each interference canceller comprises a transmitted symbol estimation part connected to a metric generator for applying a set of symbol candidates both for the at least desired and interference signals to the  
25 metric generator and for receiving metric values generated by the metric generator by using a received sub-carrier signal and said set of symbol candidates, wherein said transmitted symbol estimation part (40) determines the most likely set of symbol candidates by using the metric values.

30 In a preferred embodiment the metric generator comprises a channel parameter estimation part for estimating signal transmission channel parameters both of the at least one



desired and interference signals by using the set of the  
desired and the interference signal symbol candidates  
provided by said transmitted symbol estimation part and an  
estimation error signal provided by an error estimation part,  
5 a replica generator for generating a replica signal from both  
of the desired and the interference signals by using the set  
of the desired and the interference signal symbol candidates  
and the desired and the interference signal channel  
parameters provided by said channel parameter estimation  
10 part, wherein the error estimation part generates the  
estimation error signal by using said received sub-carrier  
signal and the replica signal and a metric calculator  
connected to the transmitted symbol estimation part for  
generating metric values from the estimation error signal.

15 The replica generator of each metric generator may  
comprise a desired signal estimation part for generating the  
replica of the desired signal by using the channel parameter  
of the desired signal and a desired signal symbol candidate  
provided by the transmitted symbol estimation part, at least  
20 one interference signal estimation part each for generating a  
replica of a respective interference signal by using the  
interference signal transmission channel parameters and  
interference signal symbol candidates provided by the  
transmitted symbol estimation part, a replica combining adder  
25 for combining the generated replicas of the desired and  
interference signals and outputting the combined replica to  
the error estimation part.

The transmitted symbol estimation part may comprise a  
first modulation signal generator for generating desired  
30 signal complex modulation symbols, at least one second  
modulation signal generator for generating interference  
signal complex modulation symbols. The replica generator of

each metric generator comprises a first complex multiplier for multiplying the output signal of the first modulation signal generator with the desired signal transmission channel parameter generated by the channel parameter estimation part, at least one second complex multiplier for multiplying the output signal of the respective second modulation signal generator with the respective interference signal transmission channel parameter generated by the channel parameter estimation part, a replica combining adder connected to said first and at least one second multiplier for summing the desired and interference signal replicas.

The transmitted symbol estimation part may further comprise a first training sequence memory unit for storing a desired signal training bit sequence and for generating a set of training bits, at least one second training sequence memory unit each of which stores an interference signal training bit sequence and each of which generates a set of training bits of a corresponding interference signal, a maximum likelihood estimator, a first switch for connecting the first training sequence memory unit during a training period and a respective output of the maximum likelihood estimator during a tracking period to the first modulation signal generator, at least a second switch for connecting the respective second training sequence memory unit during a training period and a respective output of the maximum likelihood estimator during a tracking period to the respective second modulation signal generator.

In a preferred embodiment the channel parameter estimation part comprises a channel estimator having inputs connected to the first and second modulation signal generators and to the error estimation part and outputs connected to the first and second complex multiplier

estimating and/or updating said desired and interference transmission channel parameters by using an adaptation algorithm.

In an alternative embodiment the channel parameter  
5 estimation part comprises a channel estimator having inputs connected to the first and second modulation signal generators and to a switch and outputs connected to the first and second complex multiplier, wherein the switch controllable supplies the received sub-carrier signal which is also  
10 applied to the error estimation part or the error signal generated by the error estimation part to the channel estimator.

The metric calculator may comprise an absolute-square circuit for calculating an absolute-squared value of the  
15 applied error signal.

The error estimation part may comprise a subtractor for subtracting said replica signal provided by the replica combining adder from said respectively received sub-carrier signal to generate said estimation error signal.

20 In an alternative embodiment the receiver is a multi-branch diversity receiver comprising a plurality of interference cancellers, each of which comprises a transmitted symbol estimation part connected to a number of metric generators for applying a set of symbol candidates  
25 both for the desired and interference signals to the metric generators, wherein the number of metric generators corresponds to the number of receiving branches, wherein each metric generator generates metric values by using a respective received sub-carrier signal of a different  
30 diversity branch and said set of symbol candidates, and a diversity combiner connected to the metric generators for combining the metric values received from the metric

generators, wherein said transmitted symbol estimation part determines the most likely set of symbol candidates both for the desired and interference signals to be transmitted by using the metric values received from the diversity combiner.

5        In an alternative embodiment the diversity combiner comprises a branch combining weight controller which receives a respective received sub-carrier signal on each receiving branch for computing combining weight-coefficients and outputting said weight-coefficients, a plurality of  
10 multipliers each connected to a respective metric generator, a diversity combining adder having inputs connected to the multipliers and an output connected to the transmitted symbol estimation part

      In particular, the receiver subtracts an estimated  
15 desired received sub-carrier signal and an estimated interference sub-carrier signal from a received sub-carrier signal and gets an error signal. The receiver determines transmitted signal symbol sequence both of desired and the interference signal with the error signal by using a maximum  
20 likelihood estimation device. The error signal can also be used for channel parameter estimation by using adaptation algorithms. In this receiver, both the desired and multiple of interference signals are estimated so as to minimize the estimation error signal. Hence, the receiver provides an  
25 excellent signal transmission performance even under a strong interference signal co-existence condition. This receiver can easily be extended to a multi-user receiver by outputting the estimated symbol sequences not only of the desired signal but also of the interference signals.

30        According to the present invention, a desired signal candidate which corresponds to one of the possible desired signal symbols to be transmitted and the interference signal

candidates which correspond to one of the possible signal symbols of the interference signals to be transmitted from other stations are generated in a maximum likelihood estimator. These candidates are fed to a part to generate  
5 estimated desired and interference signals (called replica signals thereafter). The desired and interference replica signals are subtracted in an error estimation part from the received signal to compute estimation error signal. The error signals are calculated for every set of desired and  
10 interference candidates. The maximum likelihood estimator selects the set of the desired signal and interference signals which has the highest likelihood metric (least estimation error). A channel parameter estimation part determines or updates the transmission channel parameters by  
15 using an adaptation algorithm so as to minimize the estimation error signal.

For the correct set of desired and interference signal symbol, both the desired signal and the interference signal components is removed, and hence the major component in the  
20 estimation error signal becomes noise and channel estimation error components. Consequently, the maximum likelihood estimation on each sub-channel is free from the influence of the interference signal. Thus, it is possible to provide an excellent receiving performance unaffected by the  
25 interference signal even if the received signal contains interference signals. According to the present invention, the desired and interference signals are treated in the same manner in terms of signal processing. Thus, this invention can be easily extended to a multi-user detection receiver if  
30 both the desired and the interference signal information sequences are output in the maximum likelihood estimator.

The features of this invention are set forth in the

appended claims. The invention, together with its objects and the advantages thereof, may be best understood by reference to the following description taken in conjunction with the accompanying drawings, in which like references numerals  
5 identify like elements in the figures and in which:

- FIG. 1A is a block diagram of a conventional transmitter using an inverse discrete Fourier transform (IDFT) in an OFDM transmission system;
- 10 FIG. 1B is a block diagram of a conventional receiver using a discrete Fourier transform (DFT) in an OFDM transmission system;
- FIG. 2A is a block diagram of an OFDM receiver using an interference canceller illustrating conceptual  
15 construction of the present invention;
- FIG. 2B is a block diagram of a parallel configuration of interference cancellers illustrating conceptual construction of the present invention;
- FIG. 2C is a block diagram of an interference canceller using  
20 a metric generator illustrating conceptual construction of the present invention;
- FIG. 3 is a block diagram of an interference canceller illustrating a conceptual block of a replica generation type of the present invention.
- 25 FIG. 4 is a block diagram of an interference canceller illustrating a replica generation type of the present invention.
- FIG. 5A is a block diagram of an OFDM two-branch diversity receiver using an interference canceller illustrating  
30 conceptual construction of the present invention;
- FIG. 5B is a block diagram of a parallel configuration of two-branch diversity interference cancellers illustrating

- conceptual construction of the present invention;
- FIG. 5C is a block diagram of an OFDM two-branch diversity receiver using an interference canceller with metric generators illustrating conceptual construction of the present invention;
- FIG. 6 is a block diagram of a two-branch diversity interference canceller illustrating a conceptual block of a replica generation type of the present invention;
- FIG. 7 is a block diagram of a two-branch diversity interference canceller illustrating a replica generation type of the present invention;
- FIG. 8 is a detailed block diagram of the interference canceller of Fig. 4;
- FIG. 9 is an alternative detailed block diagram of the interference canceller of Fig. 4;
- FIG. 10 is a detailed block diagram of the two-branch diversity interference canceller of Fig. 7;
- FIG. 11 is an alternative block diagram of the two-branch diversity interference canceller of Fig. 7;
- FIG. 12 is an alternative embodiment of the OFDM two-branch diversity receiver of Fig. 5C;
- FIG. 13 is a diagram showing an example of the configuration of a received burst signal;
- FIG. 14 is a Bit Error Rate (BER) diagram showing the effectiveness of the present invention.

A digital signal transmission multi-carrier scheme, such as an orthogonal frequency division multiplexing scheme, called OFDM scheme, reduces the effects of inter-symbol or inter-block interference by making the block period much larger than the delay spread of the radio channel. Even when

the delay spread becomes relatively large compared with the length of the OFDM block period, the use of a cyclic prefix preserves the orthogonality of the each sub-carrier channels and eliminates inter-symbol interference (ISI) or inter-block interference (IBI) between consecutive OFDM symbols. Thus, it is a great advantage for high bit rate digital signal transmissions to employ an OFDM scheme. In case of a conventional single carrier per channel (SCPC) transmission system, when the channel impulse response extends over many symbols, the number of states to be defined in a maximum likelihood sequence estimator becomes large. The number of states increases exponentially as the excess delay normalized by symbol duration increases. In case of the interference signal canceller for single carrier per channel transmission system, the number of state to be considered in a maximum likelihood sequence estimator becomes huge. Applying an OFDM scheme to a maximum likelihood sequence estimation (MLSE) receiver is very promising and effective because the OFDM scheme reduces the number of states to be considered in the MLSE receiver. By employing an OFDM scheme, the MLSE can be reduced in terms of the number of the state to be a simple maximum likelihood estimator (MLE). There is no need to perform the sequence estimation.

FIG. 2A and FIG. 2B illustrate in block diagrams the conceptual configuration of a first embodiment of a receiver 8 according to the present invention for use in a digital multi-carrier communication system such as an OFDM-system. This receiver 8, as compared with the prior art receiver of Fig. 1B, may also comprise a low pass filter 10, an analog-to-digital converter 11, a serial-to-parallel converter 12, a remove cyclic extension device 13, a discrete Fourier transform device 14, baseband demodulators and a parallel-to-



serial converter 16. In contrast to the prior art receiver which only avoids inter-symbol interferences the receiver 8 according to the present invention features a configuration wherein an interference signal canceller and signal detector part (IC) 17 is connected between the discrete Fourier transform device 14 the and parallel-to-serial converter 16. The interference signal canceller and signal detector part (IC) 17 cancels co-channel interference signals on each sub-carrier channel by generating replica signals both of the desired and interference signals. The interference signal canceller and signal detector part (IC) 17 reduces the interference and demodulates the desired signal. The outputs of the interference signal canceller and signal detector part (IC) 17 are parallel received data bit streams. The Parallel-to-Serial (P/S) converter 16 converts the parallel received data bit streams into a serial receive data bit stream.

FIG. 2B is a block diagram illustrating a concrete configuration of the embodiment of the interference canceller and signal detector part (IC) 17 in FIG. 2A. The FIG. 2B embodiment is made up of a plurality of interference cancellers (IC)  $17_1, 17_2, 17_3, \dots, 17_L$ , each of which is associated to a respective sub-carrier channel.

FIG. 2C illustrates a concrete configuration of the interference cancellers (IC) 17 shown in Fig. 2B for the  $l$ -th sub-carrier channel, where  $1 \leq l \leq L$  and  $L$  is a number of sub-carriers. In FIG. 2C, the  $l$ -th interference canceller  $17_l$  is explained as an example. A transmitted symbol estimation part 40 provides a metric generator 18 with a plurality of transmitted symbol candidates. The metric generator 18 calculates metric values by using a received signal value  $y_l(n)$  at the terminal IN and the transmitted symbol candidates and outputs the metric values which correspond to

each combination of the transmitted symbol candidates provided by transmitted symbol estimation part 40. The transmitted symbol estimation part 40 selects the most likely combination set of the transmitted symbol candidates by using  
5 the metric values provided by the metric generator 18, and outputs the most likely combination set of the transmitted symbol candidates to the terminal OUTd.

FIG. 3 shows in detail the metric generator 18 of the 1-th interference canceller 171 shown in Fig. 2C. In FIG. 3, the  
10 metric generator 18 consists of a channel estimator 50, a replica generator 20, an error estimation part 30 and a metric calculator 60. In the channel estimator 50, the channel parameter set, say, channel impulse responses both for the desired and interference signals are stored. The  
15 channel parameter set is fed to the replica generator 20. The replica generator 20 generates a replica signal of the received signals, which are the transmitted signals corrupted by transmission channel distortions such as fading and interference signals, say, co-channel signal which also  
20 corrupted by the interference signal transmission channel distortion such as fading. The error estimation part 30 calculates error signal  $e$  by using the above mentioned replica signal and the received signal at the terminal IN. The error signal  $e$  is used for the update of the channel  
25 parameters in the channel parameter estimator 50. The error signal  $e$  is also fed to the metric calculator 60. The metric calculator 60 calculates the branch metric value. The branch metric value is fed to the transmitted symbol estimation part 40. The transmitted symbol estimation part 40 provides the  
30 set of the symbol candidates to the replica generator 20 and gets the branch metric value which corresponds to the provided set of the symbol candidates, from the metric

calculator 60, as a result. Then, the transmitted symbol estimation part 40 determines the most likely combination set of the candidate to be transmitted both at the desired and the interference signal transmitters. The channel parameter estimation part 50 received the most likely set of the candidate to be transmitted and updates the channel parameters both for the desired and the interference signals by using the estimation error signal  $e$  which corresponds to the most likely set of the candidate to be transmitted. In updating channel parameters, the channel parameter estimation part 50 may employ an adaptation algorithm such as Recursive Least Squares (RLS) or Least Mean Square (LMS) algorithms. The present invention may consider co-channel interference signals as the above mentioned interference signals in a cellular or personal communication system (PCS) radio communication systems or digital audio broadcasting (DAB) and digital video broadcasting (DVB) systems. In these environments, fast channel adaptation such as RLS or LMS algorithm would be required to track the fast-time-varying channel parameters. The channel parameter estimation part 50 provides the updated channel parameters to the replica generator 20 for the next replica generation.

FIG. 4 shows an example of the replica generator 20 of the interference canceller 171. In this embodiment, for explanation convenience, the replica generator 20 consists of one desired signal estimation part 21 and two interference signal estimation parts 22<sub>1</sub> and 22<sub>2</sub>. But this scheme can be easily extended to the case where there are more than one desired and more than two interference signals. The channel parameter set is divided into the channel parameters of the desired and the interference signals. Each channel parameter is fed to the corresponding signal estimation part 21, 22<sub>1</sub>

and 22<sub>2</sub>, respectively, in the replica generator 20. The desired signal estimation part 21 generates the replica signal of the desired signal, corrupted by the desired signal transmission channel distortion such as fading, by using the  
5 desired signal estimated channel parameter and the desired signal symbol candidate. The interference signal estimation part 22<sub>1</sub> generates the replica signal of the first interference signal, called the interference signal #1 thereafter, by using the interference signal #1 estimated  
10 channel parameter and the interference signal #1 symbol candidate. The above mentioned interference signal #1 replica is corrupted by the interference signal #1 transmission channel distortion such as fading. The interference signal estimation part 22<sub>2</sub> generates the replica signal of the  
15 second interference signal, called the interference signal #2 thereafter, by using the interference signal #2 estimated channel parameter and the interference signal #2 symbol candidate. The above mentioned interference signal #2 replica is also corrupted by the interference signal #2 transmission  
20 channel distortion such as fading. In case of the multiple interference signals more than 2, the interference signal estimation part can be added to the replica generator 20, and the channel estimator 50 and the transmitted symbol estimation part 40 can also be easily extended. The replica  
25 signals, say, from 21, 22<sub>1</sub> and 22<sub>2</sub>, are summed up together in a replica combining adder 23 to be the replica signal of the received signal. The above mentioned replica signal contains the desired signal, the interference signals #1 and #2, all of which are corrupted by the corresponding transmission  
30 channel fading effects.

FIG. 5A is a block diagram illustrating a concrete configuration of a two-branch diversity receiver. This block

diagram illustrates only two-branch diversity reception scheme, but this scheme can be easily extended to the scheme that has more than two diversity branches. The received baseband signal that corresponds to a diversity branch, say  
5 diversity branch #1, is filtered with the low pass filter 10<sub>1</sub>. This low pass filter 10<sub>1</sub> can be a matched filter that corresponds to the transmitter filter in the transmitter. One example of this filter is a typical raised cosine root roll off filter. The output of the low pass filter 10<sub>1</sub> is fed to  
10 an analog-to-digital (A/D) converter 11<sub>1</sub>. The output of the analog-to-digital converter 11<sub>1</sub> is fed to a serial-to-parallel (S/P) converter 12<sub>1</sub> to get a block of received signal samples which belong to the same OFDM symbol time duration; i.e. OFDM symbol block. A cyclic extension remove  
15 unit 13<sub>1</sub> removes a cyclic prefix to alleviate the effect of inter-block interference (IBI). A discrete Fourier Transform (DFT) unit 14<sub>1</sub> transforms a block of received time-domain signal to received complex symbols corresponding to each sub-carrier channels. At the diversity branch #2, the received  
20 baseband signal is filtered with the low pass filter 10<sub>2</sub>. The output of the low pass filter is fed to the A/D converter 11<sub>2</sub>. The sampled baseband signal is converted into a block of received data samples by S/P converter 12<sub>2</sub>. A cyclic extension remove unit 13<sub>2</sub> removes the cyclic prefix and a DFT  
25 unit 14<sub>2</sub> transforms a block of time-domain received signal into received complex symbols on each sub-carrier channel. In the interference canceller and signal detector part 17, these received complex symbols are combined together on a sub-channel by sub-channel basis. The outputs of the interference  
30 signal canceller and signal detector part (IC) 17 are parallel received data bit streams. A Parallel-to-Serial

(P/S) converter 16 converts the parallel received data bit streams into a serial receive data bit stream.

FIG. 5B illustrates a block diagram of parallel configuration of the interference canceller and detector part 17. In this embodiment, diversity combining is performed sub-channel by sub-channel. There are  $L$  independent interference cancellers  $17_1 \dots 17_L$  in the interference canceller part 17, where  $L$  is the number of sub-carriers.

FIG. 5C illustrates a block diagram of the  $l$ -th interference canceller  $17_l$  of the interference canceller part 17 shown in Fig. 5B, which employs two metric generators  $18_1$ ,  $18_2$  and a diversity combiner 70 for the diversity reception. A transmitted symbol estimation part 40 generates a plural set of the desired and interference signal candidates and provides the set to the metric generators  $18_1$  and  $18_2$ . The metric generator  $18_1$  calculates metric values by using the  $l$ -th sub-channel received signal values  $y_{l,1}(n)$  at the diversity branch #1 at the terminal IN1 and the transmitted symbol candidates provided by the transmitted symbol estimation part 40, and outputs the metric values which correspond to each combination set of the transmitted symbol candidates provided by transmitted symbol estimation part 40. The metric generator  $18_2$  calculates metric values by using the  $l$ -th sub-channel received signal values  $y_{l,2}(n)$  at the diversity branch #2 at the terminal IN2 and the above mentioned transmitted symbol candidates provided by the transmitted symbol estimation part 40, and outputs the metric values which correspond to each combination of the transmitted symbol candidates provided by transmitted symbol estimation part 40. The diversity combiner 70 combines the metric values from the metric generator  $18_1$  and  $18_2$ , and outputs diversity-combined metric values to the transmitted

symbol estimation part 40. The transmitted symbol estimation part 40 selects the most likely combination set of the transmitted symbol candidates by using the diversity-combined metric value provided by the diversity combiner 70, and  
5 outputs the most likely combination set of the transmitted symbol candidates to the terminal OUTd.

FIG. 6 shows an example of the metric generators 18<sub>1</sub> and 18<sub>2</sub> of the *l*-th interference canceller 17, for two-branch diversity reception. The transmitted symbol estimation part  
10 40 provides all possible combination set of the desired and the interference symbol candidates to the metric generators 18<sub>1</sub> and 18<sub>2</sub>, one by one. At the diversity branch #1, the metric generator 18<sub>1</sub> consists of a channel estimator 50<sub>1</sub>, a replica generator 20<sub>1</sub>, an error estimation part 30<sub>1</sub> and a  
15 metric calculator 60<sub>1</sub>. In the channel estimator 50<sub>1</sub>, the channel parameter set, say, channel impulse responses both for the desired and interference signals are stored. The channel parameter set is fed to the replica generator 20<sub>1</sub>. The replica generator 20<sub>1</sub> generates the replica signal of the  
20 received signal, which is the received signal corrupted by the distortion of the desired signal transmission channel, say, fading and the interference signals, say, co-channel signal which also corrupted by the interference signal transmission channel distortion such as fading. The error  
25 estimation part 30<sub>1</sub> calculates error signal  $e_{1,m,1}$  by using the above mentioned replica signal and the *l*-th subcarrier received signal  $y_{1,1}(n)$  at diversity branch #1 at the terminal IN1. The error signal  $e_{1,m,1}$  is used for the update of the channel parameters in the channel parameter estimator 50<sub>1</sub>.  
30 The error signal  $e_{1,m,1}$  is also fed to the metric calculator 60<sub>1</sub>. The metric calculator 60<sub>1</sub> calculates a branch metric value  $b_{1,m,1}(n)$ . The branch metric value  $b_{1,m,1}(n)$  is fed to the

diversity combiner 70. At the diversity branch #2 in FIG. 6, the metric generator 18<sub>2</sub> consists of a channel estimator 50<sub>2</sub>, a replica generator 20<sub>2</sub>, an error estimation part 30<sub>2</sub>, and a metric calculator 60<sub>2</sub>. In the channel estimator 50<sub>2</sub>, the

5 channel parameter set, say, channel impulse responses both for the desired and interference signals at the diversity branch #2 are stored. The channel parameter set is fed to the replica generator 20<sub>2</sub>. The replica generator 20<sub>2</sub> generates the replica signal of the received signal, which is the

10 received signal corrupted by the distortion of the desired signal transmission channel, say, fading and the interference signals, say, co-channel signal which also corrupted by the interference signal transmission channel distortion such as fading. The error estimation part 30<sub>2</sub> calculates error signal

15  $e_{l,m,2}$  by using the above mentioned replica signal and the  $l$ -th subcarrier received signal  $y_{l,2}(n)$  at diversity branch #2 at the terminal IN2. The error signal  $e_{l,m,2}$  is used for the update of the channel parameters in the channel parameter estimator 50<sub>2</sub>. The error signal  $e_{l,m,2}$  is also fed to the

20 metric calculator 60<sub>2</sub>. The metric calculator 60<sub>2</sub> calculates the branch metric value  $b_{l,m,2}(n)$ . The branch metric value  $b_{l,m,2}(n)$  is fed to the diversity combiner 70. One embodiment example of the metric calculators 60<sub>1</sub> and 60<sub>2</sub> is absolute square circuits that calculate the absolute square value of

25 the error signals by

$$b_{l,m,j}(n) = |\varepsilon_{l,m,j}|^2. \quad (1)$$

where  $l$ ,  $m$ ,  $j$  indicate the  $m$ -th set of the desired and interference signal candidates on  $l$ -th sub-channel at diversity branch  $j$ , and  $n$  indicate the time index at  $t = nT$ .

30 The two branch metric values  $b_{l,m,1}(n)$  and  $b_{l,m,2}(n)$  are combined in the diversity combiner 70 to be a combined branch metric in FIG.6. One embodiment example of the diversity combiner 70



is an adder that sums the metric values from the metric generators 18<sub>1</sub> and 18<sub>2</sub> up together. For example, in case of two branch diversity reception scheme, the sum of the metric values  $b_{1,m,1}(n) + b_{1,m,2}(n)$  is calculated as a combined metric.

- 5 In case of  $J$  diversity branch reception, the diversity-combined metric value  $b_{l,m}(n)$  for the  $m$ -th set of the candidates on  $l$ -th sub-channel is calculated as

$$b_{l,m}(n) = \sum_{j=1}^J b_{l,m,j} \quad (2)$$

- The diversity-combined metric value  $b_{l,m}(n)$  is fed to the transmitted symbol estimation part 40. The transmitted symbol estimation part 40 selects the most likely combination set of the desired and the interference symbol candidate judging from the corresponding combined branch metric value, and outputs the most likely desired bit sequence to be transmitted as the received bit sequence to the terminal OUTd. The transmitted symbol estimation part 40 can be configured so as to output interference bit sequences for multi-user detection. The channel parameter estimation part 50<sub>1</sub> received the most likely set of the candidate to be transmitted and updates the channel parameters at the diversity branch #1 both for the desired and the interference signals by using the estimation error signal  $e_{1,m,1}$  which corresponds to the most likely set of the candidate to be transmitted. The channel parameter estimation part 50<sub>2</sub> also received the above mentioned most likely set of the candidate and updates the channel parameters at the diversity branch #2 both for the desired and the interference signals by using the estimation error signal  $e_{1,m,2}$  which corresponds to the most likely set of the candidate to be transmitted. In updating channel parameters both in the channel parameter estimation parts 50<sub>1</sub> and 50<sub>2</sub>, the channel parameter

estimation part  $50_1$  and  $50_2$  may employ an adaptation algorithm such as Recursive Least Squares (RLS) or Least Mean Square (LMS) algorithms. In this channel parameter update, the set of signal symbol candidates both of the desired and the interference signals are also used as reference signals in the adaptation algorithm. The channel parameter estimation parts  $50_1$  and  $50_2$  provide the updated channel parameters to the replica generators  $20_1$  and  $20_2$ , respectively, for the next iteration of both the transmitted symbol estimation and the channel parameter estimation. The diversity reception is effective in discriminating or canceling the interference signals because of the different characteristics of the propagation channels.

FIG. 7 shows an example of the replica generators  $20_1$  and  $20_2$  of the  $l$ -th interference canceller 171 for two-branch diversity reception. In this embodiment, the replica generator  $20_1$  consists of one desired signal estimation part  $21_1$ , at least one interference signal estimation part, say,  $22_{11}$ . In FIG. 7, one desired signal and two-interference signal case are used for explanation. But this scheme can be easily extended to the case where there are more than one desired and more than two interference signals. The channel parameter set is divided into the channel parameters of the desired and the interference signals. Each channel parameter is fed to the corresponding signal estimation part, say,  $21_1$ ,  $22_{11}$  or  $22_{21}$ , in the replica generator  $20_1$ . The desired signal estimation part  $21_1$  generates the replica signal of the desired signal, corrupted by the desired signal transmission channel distortion such as fading, by using the desired signal estimated channel parameter and the desired signal symbol candidate. The interference signal estimation part  $22_{11}$  generates the replica signal of the interference signal

#1 by using the interference signal #1 estimated channel parameter at diversity branch #1 and the interference signal #1 symbol candidate. The above mentioned interference signal #1 replica is also corrupted by the interference signal #1 transmission channel distortion such as fading. The interference signal estimation part 22<sub>1</sub> generates the replica signal of the interference signal #2 by using the interference signal #2 estimated channel parameter at diversity branch #1 and the interference signal #2 symbol candidate. The above mentioned interference signal #2 replica is also corrupted by the interference signal #2 transmission channel distortion such as fading. In case of the multiple interference signals more than 2, the interference signal estimation part can be added to the replica generator 20<sub>1</sub>, and the channel estimator 50<sub>1</sub> and the transmitted symbol estimation part 40 can be easily extended. The replica signals, say, from 21<sub>1</sub>, 22<sub>11</sub> and 22<sub>21</sub>, are summed up together in the replica combining adder 23<sub>1</sub> to be the replica signal of the received signal. The above mentioned replica signal contains the desired signal, the interference signal #1 and #2, all of which are corrupted by the corresponding transmission channel fading effects at diversity branch #1. At diversity branch #2 in FIG. 7, the replica generator 20<sub>2</sub> consists of one desired signal estimation part 21<sub>2</sub>, at least one interference signal estimation part, say, 22<sub>12</sub>. The channel parameter set, which is provided by the channel parameter estimation part 50<sub>2</sub>, is divided into the channel parameters of the desired and the interference signals. Each channel parameter is fed to the corresponding signal estimation part, say, 21<sub>2</sub>, 22<sub>12</sub> or 22<sub>22</sub>, in the replica generator 20<sub>2</sub>. The desired signal estimation part 21<sub>2</sub> generates the replica signal of the desired signal, corrupted

by the desired signal transmission channel distortion such as fading, by using the desired signal estimated channel parameter at diversity branch #2 and the desired signal symbol candidate. The interference signal estimation part  
5 22<sub>12</sub> generates the replica signal of the interference signal #1 by using the interference signal #1 estimated channel parameter at diversity branch #2 and the interference signal #1 symbol candidate. The above mentioned interference signal #1 replica is also corrupted by the interference signal #1  
10 transmission channel distortion such as fading. The interference signal estimation part 22<sub>22</sub> generates the replica signal of the interference signal #2 by using the interference signal #2 estimated channel parameter at diversity branch #2 and the interference signal #2 symbol  
15 candidate. The above mentioned interference signal #2 replica is also corrupted by the interference signal #2 transmission channel distortion such as fading. In case of the multiple interference signals more than 2, the interference signal estimation part can be added to the replica generator 20, and  
20 the channel estimator 50<sub>2</sub>. The replica signals, say, from 21<sub>12</sub>, 22<sub>12</sub> and 22<sub>22</sub>, are summed up together in the replica combining adder 23, to be the replica signal of the received signal. The above mentioned replica signal contains the  
25 desired signal, the interference signal #1 and #2, all of which are corrupted by the corresponding fading transmission channel effects at diversity branch #2.

FIG. 8 illustrates a detailed block diagram of the interference canceller 17<sub>1</sub> of Fig. 4. In FIG. 8, the desired signal and one interference signal are considered for  
30 example. A desired signal estimation part 21 and an interference signal estimation part 22 are realized by single taps (multipliers only) 210 and 220, respectively. A

transmitted symbol estimation part 40 can be realized by a modulation signal generator 41 for desired signals, the modulation signal generator 42 for the interference signal, a maximum likelihood estimator 43, training sequence memory units 81 and 82, and training/tracking mode switches 44 and 45. In the maximum likelihood estimator 43, only the present states both of the desired and interference signals are considered.

It is assumed, for example, that each radio station transmits an OFDM signal with a frame configuration as shown in FIG. 13, wherein training signal blocks are added to the beginning of an information data signal block (called pre-amble). The training signal blocks can also be placed at the intermediate portion (called mid-amble) or the end of an information data signal blocks (called post-amble). The training signal sequences are known sequence both at the transmitter and at the receiver, and are used for initial channel estimation both of the desired and the interference signals, respectively. It is preferable that the training patterns are unique patterns, which have high auto-correlation of symbol sequence of their own but have low cross-correlation value between each other. With the use of training patterns whose symbol sequence patterns are orthogonal to each other, it is possible to generate the replica signals of the desired and interference signals separately to such an extent that the replica signals have high accuracy. When a plurality of interference signals are present, their replica signals can be separately generated with high accuracy by adopting the training symbol sequences orthogonal to each other.

In the training mode, pre-known training bit sequences  $a_{1,1}(n)$  and  $a_{2,1}(n)$  for the desired and interference signals,

respectively, which are stored as training patterns in the training sequence memory units 81 and 82, respectively, are fed by the switches 44 and 45 to the modulation signal generator units 41, 42, respectively. The modulation signal generator 41 transforms or maps the desired signal bit into the complex modulation symbol  $x_{1,l}(n)$ . The modulation signal generator 42 transforms or maps the interference signal bit into complex modulation symbol  $x_{2,l}(n)$ . The output of the modulation signal generators 41 and 42 are fed to a replica generator 20 and a channel parameter estimation part 50. The replica generator 20 is, for example, made up of a single complex tap 210 which represents the desired signal transmission channel parameter  $\hat{h}_{1,l}(n-1)$ , a single complex tap 220 which represents the interference signal transmission channel parameter  $\hat{h}_{2,l}(n-1)$  and a complex adder 230 which combines the desired and the interference signal. The output value of the desired signal estimation part 21 becomes  $x_{1,l}^*(n)\hat{h}_{1,l}(n-1)$ , which represents the desired complex baseband signal corrupted by the distortion of the desired signal channel such as fading. The output value of the interference signal estimation part 22 becomes  $x_{2,l}^*(n)\hat{h}_{2,l}(n-1)$ , which represents the interference complex baseband signal corrupted by the distortion of the interference signal channel such as fading. The complex adder 230 sums these values up together to output the replica of the received signal  $x_{1,l}^*(n)\hat{h}_{1,l}(n-1) + x_{2,l}^*(n)\hat{h}_{2,l}(n-1)$ . An error estimation part 30 is realized with a subtractor 32 in this embodiment. The subtractor 32 calculates the estimation error signal  $e_l(n)$  on the  $l$ -th sub-carrier channel by

$$e_l(n) = y_l(n) - [x_{1,l}^*(n)\hat{h}_{1,l}(n-1) + x_{2,l}^*(n)\hat{h}_{2,l}(n-1)] \quad (3)$$

The estimation error signal  $e_i(n)$  is fed to the channel parameter estimation part 50. In this embodiment, the channel parameter estimation part 50 is realized with a channel estimator 51. The channel estimator 51 updates both the  
 5 desired and the interference signal transmission channel parameters  $\hat{h}_{1,i}(n-1)$  and  $\hat{h}_{2,i}(n-1)$  by using adaptation algorithm, say, Least-Mean-Squares (LMS) algorithm or Recursive Least Square (RLS) algorithm with the estimation error  $e_i(n)$ . In case of the update by LMS algorithm, an example of the  
 10 channel parameter update is performed as

$$\begin{bmatrix} \hat{h}_{1,i}(n) & \hat{h}_{2,i}(n) \end{bmatrix}^H = \begin{bmatrix} \hat{h}_{1,i}(n-1) & \hat{h}_{2,i}(n-1) \end{bmatrix}^H + \mu \begin{bmatrix} x_{1,i}(n) & x_{2,i}(n) \end{bmatrix}^H e_i(n) \quad (4)$$

The channel estimator 51 then outputs the updated channel parameters  $\hat{h}_{1,i}(n)$  and  $\hat{h}_{2,i}(n)$  as tap coefficients to the complex taps 210 and 220 for the next replica generation. After the  
 15 update of the tap coefficients, the training sequence memory units 81 and 82 output the next training bit sequences  $a_{1,i}(n+1)$  and  $a_{2,i}(n+1)$  to the modulation signal generators 41 and 42 through the switches 44 and 45. The above mentioned replica generation process in the replica generator 20, the  
 20 error estimation process in the error estimation part 30 and the channel parameter update process in the channel estimator 50 are iteratively performed until the end of the training sequence. As the results, at the end of the training sequence, the channel parameters converge in the channel  
 25 parameters which represent the real transmission channel properties. The training mode is a process to get the channel parameters of the desired and the interference signal transmission channels with the training sequences.

After the training mode, the tracking mode begins to  
 30 work. In the tracking mode, the information data signal blocks in FIG. 13 are processed. During the tracking mode,

the switches 44 and 45 connect the maximum likelihood estimator 43 to the modulation signal generators 41 and 42. The maximum likelihood estimator 43 outputs sequentially all the combination set of the desired and the interference signal bit patterns  $a_{1,1,m}(n)$  and  $a_{2,1,m}(n)$  to the modulation signal generators 41 and 42, where  $m$  is an index to the possible set of the desired and the interference signal bit patterns. For all values of  $m$ , that is, all possible combination sets of the desired and the interference signal bit patterns, the following process is performed:

- (1) The modulation signal generator 41 transforms or maps the desired signal bit patterns  $a_{1,1,m}(n)$  into complex modulation symbol  $x_{1,1,m}(n)$ . The modulation signal generator 42 transforms or maps the interference signal bit patterns  $a_{2,1,m}(n)$  into complex modulation symbol  $x_{2,1,m}(n)$ .
- (2) The output of the modulation signal generators 41 and 42 are fed to the replica generator 20 and the channel parameter estimation part 50.
- (3) The replica generator 20 generates the replica signal. The single complex tap 210 stores the desired signal transmission channel parameter  $\hat{h}_{1,j}(n-1)$  which was obtained at the former iteration. The single complex tap 220 stores the interference signal transmission channel parameter  $\hat{h}_{2,j}(n-1)$  which was obtained at the former iteration. In case of the very beginning of the tracking mode, the channel parameters obtained during the training mode are used. The complex tap 210 calculates the value  $x_{1,j,m}(n)\hat{h}_{1,j}(n-1)$  which represents the desired complex baseband signal corrupted by the distortion of the desired signal channel such as fading. The complex tap 220 calculates the value



5  $x_{1,l,m}^*(n)\hat{h}_{1,l}(n-1)$  which represents the interference complex baseband signal corrupted by the distortion of the interference signal channel such as fading. The complex adder 230 sums these values up together to output the replica  $\hat{y}_{l,m}(n)$  of the received signal as

$$\hat{y}_{l,m}(n) = x_{1,l,m}^*(n)\hat{h}_{1,l}(n-1) + x_{2,l,m}^*(n)\hat{h}_{2,l}(n-1). \quad (5)$$

(4) The error estimation part 30 calculates the estimation error signal. The subtractor 32 calculates the estimation error signal  $e_{l,m}(n)$  on the  $l$ -th sub-carrier channel by

$$e_{l,m}(n) = y_l(n) - \hat{y}_{l,m}(n) \quad (6)$$

(5) The error signal  $e_{l,m}(n)$  is fed to the metric calculator 60. In the metric calculator 60, the absolute-square circuit 61 calculates branch metric  $b_{l,m}(n)$  by

$$b_{l,m}(n) = |e_{l,m}(n)|^2. \quad (7)$$

where  $l$  and  $m$  indicate the  $m$ -th set of the desired and interference signal candidates on  $l$ -th sub-channel.

The maximum likelihood estimator 43 selects the most likely set  $a_{1,1}(n)$  and/or  $a_{2,1}(n)$  of the desired and interference signal candidates and outputs to the terminal OUTd. In case of the branch metric defined in equation (7), the maximum likelihood estimator 43 selects the most likely set  $a_{1,1,m}(n)$  and/or  $a_{2,1,m}(n)$  so as to minimize the  $b_{l,m}(n)$  with regard to the index  $m$ . The estimation error signal  $e_{l,m'}(n)$  is fed to the channel parameter estimation part 50, where  $m'$  gives the minimum  $b_{l,m}(n)$  value in equation (7) for all possible  $m$ 's. The channel estimator 51 updates both the desired and the interference signal transmission channel parameters  $\hat{h}_{1,l}(n-1)$  and  $\hat{h}_{2,l}(n-1)$  by using adaptation algorithm, say, Least-Mean-Squares (LMS) algorithm or Recursive Least

Square (RLS) algorithm with the estimation error  $e_{l,m}(n)$  and the selected set of  $a_{1,l,m}(n)$  and/or  $a_{2,l,m}(n)$ . In case of updating by LMS algorithm, an example of the channel parameter update is performed as

$$5 \quad \begin{bmatrix} \hat{h}_{1,l}(n) & \hat{h}_{2,l}(n) \end{bmatrix}^H = \begin{bmatrix} \hat{h}_{1,l}(n-1) & \hat{h}_{2,l}(n-1) \end{bmatrix}^H + \mu \begin{bmatrix} x_{1,l,m}(n) & x_{2,l,m}(n) \end{bmatrix}^H \varepsilon_{l,m}(n) \quad (8)$$

where  $m$  is a step size parameter.

The channel estimator 51 then outputs the updated channel parameters  $\hat{h}_{1,l}(n)$  and  $\hat{h}_{2,l}(n)$  as tap coefficients to the complex taps 210 and 220 for the next replica generation. After the  
 10 update of the tap coefficients, the maximum likelihood estimator 43 outputs sequentially all the combination set of the desired and the interference signal bit patterns  $a_{1,l,m}(n+1)$  and  $a_{2,l,m}(n+1)$  to the modulation signal generators 41 and 42, where  $m$  is an index to the possible set of the  
 15 desired and the interference signal bit patterns. For all values of  $m$ , the above mentioned processes from (1) to (5) are performed again. When the transmission channels do not vary fast in time, the channel parameter update process during the tracking mode can be stopped.

20 For generalization, it is assumed that a desired signal station user and  $(K-1)$  interference signal station users exist on the same OFDM channel. Let the channel transfer function on  $l$ -th sub-carrier of  $k$ -th user be  $h_{k,l}$ , the received signal on the  $l$ -th sub-carrier channel can be  
 25 expressed as follows;

$$y_l(n) = \sum_{k=1}^K h_{k,l}(n) x_{k,l}(n) + n_l(n) \quad (9)$$

where  $y_l(n)$  is the received signal on the  $l$ -th sub-carrier,  $x_{k,l}(n)$  is the transmitted symbol on  $l$ -th sub-carrier of  $k$ -th user, and  $n_l(n)$  is filtered thermal noise on the  $l$ -th sub-carrier. The index  $n$  indicate the  $n$ -th time instant. FIG. 8  
 30 corresponds to the concrete embodiment in case of  $K=2$ .

During the training mode, the training process is performed. In this process, the switches 44 and 45 are connected to the individual training sequence memory units (81 and 82) which store the known training sequence, in order to make the tap coefficients  $\hat{h}_{k,l}(n)$  converge into the values which represent the channel transfer function of the corresponding desired and interference signal transmission channels. The modulation signal generators 41 and 42 generate corresponding training complex modulation symbols  $x_{k,l}(n)$ .

These symbols are fed to the multipliers 21 and 22. The output of the multipliers 210 and 220 become the replica signals of the desired and interference signals, respectively. These replica signals are summed up together at the adder 230 to become the replica signal  $\hat{y}_l(n)$  of the received signal which are the mixture of the desired and the interference signals as

$$\hat{y}_l(n) = \sum_{k=1}^K x_{k,l}^*(n) \hat{h}_{k,l}(n-1) \quad (10)$$

where  $*$  denotes complex conjugation.  $\hat{h}_{k,l}(n-1)$  and  $x_{k,l}(n)$  denote, respectively, the  $k$ -th user's estimated complex channel response at time instant  $(n-1)T$  and the modulation training symbol of the  $k$ -th user on  $l$ -th sub-channel at time instant  $nT$ .  $T$  is the OFDM block duration.

This replica signal  $\hat{y}_l(n)$  is subtracted at the subtractor 32 from the actual received signal  $y_l(n)$  and the error signal  $e_l(n)$  on  $l$ -th sub-carrier channel is obtained as follows;

$$e_l(n) = y_l(n) - \hat{y}_l(n) \quad (11)$$

The estimated channel response vector (tap coefficient vector)  $\mathbf{H}_l(n)$  both for the desired and  $(K-1)$  interference signals is given by

$$\mathbf{H}_l^H(n) = [\hat{h}_{1,l}^* n \quad \hat{h}_{2,l}^* n \quad \dots \quad \hat{h}_{K,l}^* n] \quad (12)$$

where  $^H$  denotes complex conjugation and transposition. Similarly, the modulation training symbol vector  $\mathbf{X}_1(n)$  for the desired and  $(K-1)$  interference signals is given by

$$\mathbf{X}_1^H(n) = [x_{1,1}^*(n), x_{1,2}^*(n), \dots, x_{1,K}^*(n)] \quad (13)$$

5 The channel estimator 51 updates the estimated channel response vector  $\mathbf{H}_1(n)$  by an adaptation algorithm such as RLS, LMS or a similar adaptation algorithm. Here, for example, the update of the estimated channel response vector  $\mathbf{H}_1(n)$  using the LMS algorithm is explained. The channel estimator 51  
10 updates the channel response vector  $\mathbf{H}_1(n)$  using both the known modulation training symbol vector  $\mathbf{X}_1(n)$  and the error signal  $e_1(n)$  as follows;

$$\mathbf{H}_1^H(n) = \mathbf{H}_1^H(n-1) + \mu \mathbf{X}_1^H(n) e_1(n) \quad (14)$$

where  $\mu$  is a step size parameter.

15 After the above mentioned training process, the information data signal block is processed. At the beginning of the information data signal period, the estimated channel response  $\mathbf{H}_1(n-1)$  obtained in the training process is used as a initial value of the estimated channel response vector  
20  $\mathbf{H}_1(n-1)$ .

The maximum likelihood estimator 43 outputs the possible combinations of the desired signal and the interference signal bit candidates to the modulation signal generators 41 and 42. This combination set of the desired signal and the  
25 interference signal complex modulation symbols can be expressed as the modulation vector candidate  $\mathbf{X}_{1,m}(n)$  for the desired and  $(K-1)$  interference signals on the  $l$ -th sub-carrier channel with a candidate index number of  $m$  as follows;

$$\mathbf{X}_{1,m}^H(n) = [x_{1,1,m}^*(n), x_{1,2,m}^*(n), \dots, x_{1,K,m}^*(n)] \quad (15)$$

where  $m$  is a combined symbol index number (possible candidate number) defined as follows;

$$m = \sum_{k=1}^K M^{k-1} m_k \quad (16)$$

where  $M$  is a number of messages, for example  $M = 4$  in case of QPSK signaling, and  $m_k$  is the  $k$ -th user signal message symbol index number which is an integer of  $0 \leq m_k \leq (M-1)$ , thus  $m$  takes an integer value ranging  $0 \leq m \leq (M^K-1)$ .

For example, in case of BPSK signaling modulation, the complex message symbol  $x_{k,l,m_k}(n)$  at the time instant  $nT$  is as follows;

$$\begin{aligned} x_{k,l,m_k}(n) &= 1 \quad (m_k = 0) \\ &= -1 \quad (m_k = 1) \end{aligned} \quad (17)$$

Hence with two users, i.e. the desired signal station and one interference signal station, the modulation vector candidate  $\mathbf{X}_{l,m}(n)$  ( $0 \leq m \leq 3$ ) at time instant  $nT$  takes one of the following vectors;

$$\begin{aligned} \mathbf{X}_{l,0}^H(n) &= [1 \quad 1] \\ \mathbf{X}_{l,1}^H(n) &= [1 \quad -1] \\ \mathbf{X}_{l,2}^H(n) &= [-1 \quad 1] \\ \mathbf{X}_{l,3}^H(n) &= [-1 \quad -1] \end{aligned} \quad (18)$$

In the case of QPSK signaling modulation, for example, the complex message symbol  $x_{k,l,m_k}(n)$  at the time instant  $nT$  is as follows;

$$\begin{aligned} x_{k,l,m_k}(n) &= \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \quad (m_k = 0) \\ &= -\frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \quad (m_k = 1) \\ &= -\frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \quad (m_k = 2) \\ &= \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \quad (m_k = 3) \end{aligned} \quad (19)$$

Hence in case of QPSK signaling modulation with two users, the modulation vector candidates  $\mathbf{X}_{l,m}(n)$  ( $0 \leq m \leq 15$ ) at time instant  $nT$  are the following vectors;

$$x_{l,0}^H(n) = \left[ \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,1}^H(n) = \left[ \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,2}^H(n) = \left[ \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,3}^H(n) = \left[ \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \right]$$

5

$$x_{l,4}^H(n) = \left[ -\frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,5}^H(n) = \left[ -\frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,6}^H(n) = \left[ -\frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,7}^H(n) = \left[ -\frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \right]$$

10

$$x_{l,8}^H(n) = \left[ -\frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,9}^H(n) = \left[ -\frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \right] \quad (20)$$

$$x_{l,10}^H(n) = \left[ -\frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,11}^H(n) = \left[ -\frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,12}^H(n) = \left[ \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \right]$$

15

$$x_{l,13}^H(n) = \left[ \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} + j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,14}^H(n) = \left[ \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \right]$$

$$x_{l,15}^H(n) = \left[ \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} - j \frac{1}{\sqrt{2}} \right]$$

5 The replica signal of the received signal at the output of the adder 230 becomes  $X_{l,m}^H(n) \cdot H_l(n)$ . The error signal  $e_{l,m}(n)$  for  $m$ -th candidate on the  $l$ -th sub-carrier channel becomes as follows;

$$e_{l,m}(n) = y_l - X_{l,m}^H(n) \cdot H_l(n) \quad (21)$$

10 The absolute-squared error signal  $|e_{l,m}(n)|^2$  is calculated for each candidate index  $m$  in the metric calculation part 61 and is used as a metric  $b_{l,m}(n)$  in the maximum likelihood estimator 43 to determine the most likely candidate so as to minimize the squared error signal value  $b_{l,m}(n)$  as follows;

$$15 \quad b_{l,m_{\min}}(n) = \underset{m}{\text{Min}} \left( |e_{l,m}(n)|^2 \right) \quad (22)$$

where  $m_{\min}$  is the index  $m$  which gives the minimum value of  $b_{l,m}(n)$ . The set of the desired and interference signals which has been transmitted most likely as complex symbols can be determined with  $m_{\min}$  according the index number defined in the  
20 equation (16).

When the transmission channel variation is relatively slow compared to the OFDM symbol rate, the channel response vector  $H_l(n)$  can be used constantly even in the information data signal block. The channel response vector update process can  
25 be stopped after the training process. This case further can reduce the complexity of the embodiment in terms of the signal processing.

When the transmission channel varies very rapidly, such as the mobile radio channel for example, the channel response

vector  $H_1(n)$  can be updated OFDM-block-by-block by using an adaptation algorithm, such as RLS, LMS or other similar adaptation algorithms. Here, the update of the channel response vector  $H_1(n)$  by the LMS algorithm is explained as an example. During the information data signal blocks, the channel estimator 51 updates the estimated channel response vector  $H_1(n)$  using both the determined modulation symbol vector  $X_{l,m_{\min}}(n)$  and the error signal  $\varepsilon_{l,m_{\min}}(n)$  obtained for the candidate having the index  $m_{\min}$  as follows;

$$H_1^n(n) = H_1^n(n-1) + \mu X_{l,m_{\min}}^H(n) \varepsilon_{l,m_{\min}}(n) \quad (23)$$

where  $\mu$  is a step size parameter.

The updated channel response vector  $H_1(n)$  is used for the replica generation at next step in Equation (21). The extension to the case where a plurality of the interferer is present, is straightforward by adding extra interference signal estimation parts same as 22, and modulated signal generating parts, same as 42.

FIG. 9 illustrates another embodiment of the interference canceller of Fig. 4. In FIG. 9, the channel parameter estimation part 50 is realized with another channel estimator 52. An example of the channel estimator 52 is a complex correlator which calculates complex cross-correlation between the received signal and the training sequence and determines the channel parameters. In this embodiment, during the training mode, the switch 44 and 45 connect the training sequence memory units 81 and 82 to the modulation signal generators 41 and 42, respectively in order to provide the complex modulation symbols  $x_{1,1}(n)$  and  $x_{2,1}(n)$  to the channel estimator 52. The received-signal/error-signal switch 53 connects the channel estimator 52 to a terminal IN in order for the channel estimator 52 to get the received signal  $y_1(n)$ . In the channel estimator 52, cross-correlation between



the received signal  $y_1(n)$  and the complex modulation symbols both of the desired and the interference signal are calculated over the training period, and then the tap coefficients both for the desired and the interference signal are determined. In the tracking mode, the received-signal/error-signal switch 53 connects the channel estimator 52 to the subtractor 32 so that the channel estimator 52 gets an estimation error signal. In the tracking mode, this embodiment works in the same manner as the embodiment described in FIG. 8. When the transmission channels do not vary fast in time, the channel parameter update process during the tracking mode can be stopped. The channel parameters can be used during the tracking mode in which the information data signal blocks are sent.

FIG. 10 illustrates a concrete embodiment of the two-branch diversity interference canceller of Fig. 7. In FIG. 10, there are two metric generators  $18_1$  and  $18_2$ , each of which consists of the channel parameter estimation parts  $50_1$  and  $50_2$ , respectively, the desired signal estimation part  $21_1$  and  $21_2$ , the interference signal estimation parts  $22_1$  and  $22_2$ , and the error estimation part  $30_1$  and  $30_2$ . In case of a  $J$ -branch diversity reception scheme, there are  $J$  metric generators;  $17_1, 17_2, \dots, 17_J$ . In FIG. 10 let the  $j$ -th input received signal at the  $j$ -th metric generator input terminal  $IN_j$ , the  $j$ -th error signal, the  $j$ -th channel response vector and the  $j$ -th modulation vector at the time instant  $nT$  be  $y_{1,j}(n)$ ,  $e_{1,j}(n)$ ,  $H_{1,j}(n)$  and  $X_1(n)$ , the error signal  $e_{1,m,j}(n)$  on the  $l$ -th sub-carrier channel during the training period is calculated by the following equation;

$$e_{1,j}(n) = y_{1,j}(n) - X_1^H(n) \cdot H_{1,j}(n-1) \quad (24)$$

where  $X_l^H(n)$  is provide by training sequence memory units 81 and 82 and is written by the same equation as the equation (13). The  $j$ -th channel response vector  $H_{l,j}(n)$  is written by

$$H_{l,j}^H(n) = [\hat{h}_{1,j}^* n \quad \hat{h}_{2,j}^* n \quad \dots \quad \hat{h}_{K,j}^* n] , \quad (25)$$

5 where  $^H$  denotes complex conjugation and transposition and  $\hat{h}_{k,j}(n)$  denotes the  $k$ -th user's channel response at the  $j$ -th diversity branch on  $l$ -th sub-channel.

The  $j$ -th channel estimator 51j updates the  $j$ -th channel response vector  $H_{l,j}(n)$  by adaptation algorithm such as LMS, 10 RLS, or other similar adaptation algorithm. We explain here, for example, the update by LMS algorithm. The channel estimator 51j updates the channel response vector  $H_{l,j}(n)$  using the known modulation training symbol vector  $X_l(n)$  and the error signal  $\varepsilon_{l,j}(n)$  as follows;

$$15 \quad H_{l,j}^H(n) = H_{l,j}^H(n-1) + \mu X_l^H(n) \varepsilon_{l,j}(n) \quad (26)$$

where  $\mu$  is a step size parameter.

In tracking mode, let the  $m$ -th modulation vector candidate on the  $l$ -th subcarrier channel at the time instant  $nT$  be  $X_{l,m}(n)$ , the  $m$ -th estimation error signal  $e_{l,m,j}(n)$  on the  $l$ -th 20 subcarrier channel at the  $j$ -th diversity branch is calculated by the following equation;

$$\varepsilon_{l,m,j}(n) = y_{l,j} - X_{l,m}^H(n) \cdot H_{l,j}(n-1) \quad (27)$$

The metric combiner 71 sums up together the  $m$ -th candidate squared error signals  $|\varepsilon_{l,m,j}(n)|^2$  to perform diversity combining 25 by the following equation;

$$b_{l,m}(n) = \sum_{j=1}^J |\varepsilon_{l,m,j}(n)|^2 \quad (28)$$

The maximum likelihood estimator 43 determines the most likely candidate so as to minimize the combined metric  $b_{l,m}(n)$  which was calculated by equation (28), as follows;

$$30 \quad b_{l,\text{min}}(n) = \min_m b_{l,m}(n) \quad (29)$$

where  $m_{\min}$  is the index  $m$  which gives the minimum value of  $b_{1,m}(n)$ . The set of the desired and interference signals which most likely has been transmitted as complex symbols can be determined with  $m_{\min}$  according to the index number defined in the equation (16). When the transmission channels do not vary fast in time, the channel parameter update process during the tracking mode can be stopped. The channel parameters can be used during the tracking mode in which the information data signal blocks are sent. When the transmission channels vary fast in time, the channel parameters can be updated during tracking mode, the channel estimator 51<sub>j</sub> updates the channel response vector  $\mathbf{H}_{1,j}(n-1)$  using the determined modulation symbol vector  $\mathbf{X}_{1,m_{\min}}(n)$  and the error signal  $\varepsilon_{1,m_{\min},j}(n)$  as follows;

$$\mathbf{H}_{1,j}^H(n) = \mathbf{H}_{1,j}^H(n-1) + \mu \mathbf{X}_{1,m_{\min}}^H(n) \varepsilon_{1,m_{\min},j}(n) \quad (30)$$

where  $m$  is a step size parameter.

FIG. 11 illustrates an alternative embodiment of the two-branch diversity interference canceller of Fig. 7. In FIG. 11, the channel parameter estimation parts 50<sub>1</sub> and 50<sub>2</sub> are realized with other channel estimators 52<sub>1</sub> and 52<sub>2</sub>, respectively. An example of the channel estimators 52<sub>1</sub> and 52<sub>2</sub> are complex correlators which calculate complex cross-correlation between the received signal and the training sequence, and which determine the channel parameters. In this embodiment, during the training mode, the switches 44 and 45 connect the training sequence memory units 81 and 82 to the modulation signal generators 41 and 42, respectively in order to provide the complex modulation symbols  $x_{1,1}(n)$  and  $x_{2,1}(n)$  to the channel estimators 52<sub>1</sub> and 52<sub>2</sub>. The received-signal/error signal switches 53<sub>1</sub> and 53<sub>2</sub> connect the channel estimators 52<sub>1</sub> and 52<sub>2</sub> to the terminal IN1 and IN2 so that the channel estimators 52<sub>1</sub> and 52<sub>2</sub> get the received signal  $y_{1,1}(n)$  and  $y_{1,2}(n)$ , respectively. In the channel estimator

52<sub>1</sub>, cross-correlation between the received signal  $y_{1,1}(n)$  and the complex modulation symbols, say,  $x_{1,1}(n)$  and  $x_{2,1}(n)$  of the desired and the interference signals, respectively, are calculated over the training period, and then the tap

5 coefficients, say,  $\hat{h}_{1,1}(n-1)$  and  $\hat{h}_{2,1}(n-1)$  for the desired and the interference signal, respectively, are determined. In the channel estimator 52<sub>2</sub>, cross-correlation between the received signal  $y_{1,2}(n)$  and the complex modulation symbols  $x_{1,1}(n)$  and  $x_{2,1}(n)$  of the desired and the interference signals,

10 respectively, are calculated over the training period, and then the tap coefficients, say,  $\hat{h}_{1,2}(n-1)$  and  $\hat{h}_{2,2}(n-1)$  for the desired and the interference signal, respectively, are determined.

In the tracking mode, the received-signal/error-signal

15 switches 53<sub>1</sub> and 53<sub>2</sub> connect the channel estimators 52<sub>1</sub> and 52<sub>2</sub> to the subtractors 32<sub>1</sub> and 32<sub>2</sub> so that the channel estimators 52<sub>1</sub> and 52<sub>2</sub> get estimation error signals. In the tracking mode, this embodiment works in the same manner as, say, the embodiment described in FIG. 10. When the

20 transmission channels do not vary fast in time, the channel parameter update process during the tracking mode can be stopped. The channel parameters can be used during the tracking mode in which the information data signal blocks are sent.

25 FIG. 12 illustrates an alternative embodiment of the OFDM two-branch diversity receiver of Fig. 5C. In FIG. 12, another embodiment of the diversity combiner 70 is depicted. The diversity combiner 70 is made up of a diversity combining adder 71, multipliers 72<sub>1</sub> and 72<sub>2</sub>, a branch combining weight

30 controller 73. The branch combining weight controller 73 receives channel information of received signals at diversity branches such as received signal strength information or

other interference strength information, and determines weight-coefficients that weight each metric value of the diversity branch. The multipliers 72<sub>1</sub> and 72<sub>2</sub> receive weight-coefficients from the branch combining weight controller.

5 Then, the multipliers 72<sub>1</sub> and 72<sub>2</sub> multiply each metric value from each metric generator by corresponding weight-coefficient, and output metric values to the adder 71. The adder 71 sums the weighted metric values up together and outputs a combined metric value to the transmitted symbol  
10 estimation part 40.

FIG. 14 depicts the bit error rate (BER) performance of the present invention showing the effectiveness of the present invention. FIG. 14 shows that the average bit error rate of a receiver according to the present invention under  
15 the Rayleigh fading condition is less than  $1.0 \times 10^{-2}$  for average Carrier-to-Interference Ratio (CIR) = -5 dB, where the Co-Channel Interference (CCI) signal is stronger than the desired signal by 5 dB. The effectiveness of the present invention can also be shown by the fact that the average BER  
20 value of the receiver according to the present invention at an average CIR of 0 dB is less than  $1.0 \times 10^{-2}$  while that of a conventional signal detector in an OFDM receiver is 0.5.

Claims

1. A receiver for use in a digital multi-carrier communication system, comprising
  - 5 a) at least one receiving branch (#1, #2), wherein each receiving branch comprises demodulating means ( $0; 0_1, 0_2$ ) for converting a received serial multi-carrier signal including at least one desired and interference signal into a plurality ( $L$ ) of sub-carrier signals,  
10 and
  - b) a plurality ( $L$ ) of interference cancellers ( $17_1-17_L$ ) each of which is associated to a respective one of said sub-carrier signals for canceling co-channel interference.
- 15 2. The receiver according to claim 1, wherein the digital multi-carrier communication system is an OFDM-system.
3. The receiver according to claim 2, wherein each
  - 20 demodulating means ( $0; 0_1, 0_2$ ) comprises a serial-to-parallel converter ( $12; 12_1, 12_2$ ) for converting the received serial multi-carrier signal into parallel OFDM signal blocks,  
means for removing cyclic extensions inserted into the multi-carrier signal to be transmitted to remove inter-  
25 block interference,  
Discrete Fourier Transform means for converting each OFDM signal block into a plurality of OFDM sub-carrier signals, and wherein  
30 the outputs of the interference cancellers ( $17_1-17_L$ ) are fed to a serial-to-parallel converter (16).

4. The receiver of any one of claims 1 to 3, wherein each interference canceller (17<sub>1</sub>-17<sub>L</sub>) comprises a transmitted symbol estimation part (40) connected to a metric generator (18; 18<sub>1</sub>, 18<sub>2</sub>) for applying a set of symbol candidates both for the at least desired and interference signals to the metric generator (18; 18<sub>1</sub>, 18<sub>2</sub>) and for receiving metric values generated by the metric generator (18; 18<sub>1</sub>, 18<sub>2</sub>) by using a received sub-carrier signal and said set of symbol candidates, wherein said transmitted symbol estimation part (40) determines the most likely set of symbol candidates by using the metric values.
5. The receiver of claim 4, wherein the metric generator (18; 18<sub>1</sub>, 18<sub>2</sub>) comprises a channel parameter estimation part (50; 50<sub>1</sub>, 50<sub>2</sub>) for estimating signal transmission channel parameters both of the at least one desired and interference signals by using the set of the desired and the interference signal symbol candidates provided by said transmitted symbol estimation part (40) and an estimation error signal provided by an error estimation part (30; 30<sub>1</sub>, 30<sub>2</sub>), a replica generator (20; 20<sub>1</sub>, 20<sub>2</sub>) for generating a replica signal from both of the desired and the interference signals by using the set of the desired and the interference signal symbol candidates and the desired and the interference signal channel parameters provided by said channel parameter estimation part (50; 50<sub>1</sub>, 50<sub>2</sub>), wherein said error estimation part (30; 30<sub>1</sub>, 30<sub>2</sub>) generates the estimation error signal by using said received sub-carrier signal and the replica signal

and a metric calculator (60, 60<sub>1</sub>, 60<sub>2</sub>) connected to said transmitted symbol estimation part (40) for generating metric values from the estimation error signal.

- 5     6.     The receiver of claim 5, wherein the replica generator (20; 20<sub>1</sub>, 20<sub>2</sub>) of each metric generator (18; 18<sub>1</sub>, 18<sub>2</sub>) comprises
- 10     a desired signal estimation part (21; 21<sub>1</sub>, 21<sub>2</sub>) for generating the replica of the desired signal by using the channel parameter of the desired signal and a desired signal symbol candidate provided by the transmitted symbol estimation part (40),
- 15     at least one interference signal estimation part (22<sub>1</sub>, 22<sub>2</sub>) each for generating a replica of a respective interference signal by using the interference signal transmission channel parameters and interference signal symbol candidates provided by the transmitted symbol estimation part (40),
- 20     a replica combining adder (23; 23<sub>1</sub>, 23<sub>2</sub>) for combining the generated replicas of the desired and interference signals and outputting the combined replica to the error estimation part (30; 30<sub>1</sub>, 30<sub>2</sub>).

- 25     7.     The receiver of claim 4, 5 or 6, wherein the transmitted symbol estimation part (40) comprises a first modulation signal generator (41) for generating desired signal complex modulation symbols
- 30     at least one second modulation signal generator (42) for generating interference signal complex modulation symbols, and wherein the replica generator (20; 20<sub>1</sub>, 20<sub>2</sub>) of each metric generator (18; 18<sub>1</sub>, 18<sub>2</sub>) comprises



a first complex multiplier (210; 210<sub>1</sub>, 210<sub>2</sub>) for multiplying the output signal of the first modulation signal generator (41) with the desired signal transmission channel parameter generated by the channel parameter estimation part (50; 50<sub>1</sub>, 50<sub>2</sub>),  
5 at least one second complex multiplier (220; 220<sub>1</sub>, 220<sub>2</sub>) for multiplying the output signal of the respective second modulation signal generator (41) with the respective interference signal transmission channel parameter generated by the channel parameter estimation part (50; 50<sub>1</sub>, 50<sub>2</sub>),  
10 a replica combining adder (230; 230<sub>1</sub>, 230<sub>2</sub>) connected to said first and at least one second multiplier for summing the desired and interference signal replicas.

15

8. The receiver of claim 7, wherein the transmitted symbol estimation part (40) comprises  
a first training sequence memory unit (81) for storing a desired signal training bit sequence and for generating a  
20 set of training bits  
at least one second training sequence memory unit (82) each of which stores an interference signal training bit sequence and each of which generates a set of training bits of a corresponding interference signal,  
25 a maximum likelihood estimator (43),  
a first switch (44) for connecting the first training sequence memory unit (81) during a training period and a respective output of the maximum likelihood estimator (43) during a tracking period to the first modulation  
30 signal generator (41),  
at least a second switch (45) for connecting the respective second training sequence memory unit (81)

during a training period and a respective output of the maximum likelihood estimator (43) during a tracking period to the respective second modulation signal generator (41).

5

9. The receiver of claim 8, wherein the channel parameter estimation part (50; 50<sub>1</sub>, 50<sub>2</sub>) comprises a channel estimator (51; 51<sub>1</sub>, 51<sub>2</sub>) having inputs connected to the first and second modulation signal generators (41, 42) and to the error estimation part (30; 30<sub>1</sub>, 30<sub>2</sub>) and outputs connected to the first and second complex multiplier (210; 210<sub>1</sub>, 210<sub>2</sub>) for estimating and/or updating said desired and interference transmission channel parameters by using an adaptation algorithm.

15

10. The receiver of claim 9, wherein the adaption algorithm is a recursive adaption algorithm, a Recursive-Least-Squares (RLS) algorithm or a Least-Mean-Square (LMS) algorithm.

20

11. The receiver of claim 8, wherein the channel parameter estimation part (50; 50<sub>1</sub>, 50<sub>2</sub>) comprises a channel estimator (52; 52<sub>1</sub>, 52<sub>2</sub>) having inputs connected to the first and second modulation signal generators (41, 42) and to a switch (53; 53<sub>1</sub>, 53<sub>2</sub>) and outputs connected to the first and second complex multiplier (210; 210<sub>1</sub>, 210<sub>2</sub>), wherein said switch controllable supplies the received sub-carrier signal which is also applied to the error estimation part (30; 30<sub>1</sub>, 30<sub>2</sub>) or the error signal generated by the error estimation part (30; 30<sub>1</sub>, 30<sub>2</sub>) to the channel

30

estimator (52; 52<sub>1</sub>, 52<sub>2</sub>).

12. The receiver of anyone of the claims 1 to 11, wherein  
the metric calculator (60; 60<sub>1</sub>, 60<sub>2</sub>) comprises  
5 an absolute-square circuit (61; 61<sub>1</sub>, 61<sub>2</sub>) for  
calculating an absolute-squared value of the applied  
error signal.

13. The receiver of anyone of the claims 5 to 12, wherein  
10 the error estimation part (30; 30<sub>1</sub>, 30<sub>2</sub>) comprises  
a subtractor (32; 32<sub>1</sub>, 32<sub>2</sub>) for subtracting said replica  
signal provided by the replica combining adder (230;  
230<sub>1</sub>, 230<sub>2</sub>) from said respectively received sub-carrier  
signal to generate said estimation error signal.

15

14. The receiver of any one of the claims 1 to 13, wherein  
the receiver is a multi-branch diversity receiver  
comprising a plurality (L) of interference cancellers  
(17<sub>1</sub>-17<sub>L</sub>), each of which comprises  
20 a transmitted symbol estimation part (40) connected to a  
number (#1, #2)) of metric generators (18<sub>1</sub>, 18<sub>2</sub>) for  
applying a set of symbol candidates both for the desired  
and interference signals to the metric generators (18;  
18<sub>1</sub>, 18<sub>2</sub>), wherein the number of metric generators  
25 corresponds to the number of receiving branches, wherein  
each metric generator (18; 18<sub>1</sub>, 18<sub>2</sub>) generates metric  
values by using a respective received sub-carrier signal  
of a different diversity branch and said set of symbol  
candidates, and  
30 a diversity combiner (70) connected to said metric  
generator (40) for combining the metric values received  
from the metric generators (18<sub>1</sub>, 18<sub>2</sub>), wherein said

transmitted symbol estimation part (40) determines the most likely set of symbol candidates both for the desired and interference signals to be transmitted by using the metric values received from the diversity combiner.

5

15. The receiver of claim 14, wherein the diversity combiner (70) comprises a diversity combining adder (71).

10

16. The receiver of claim 14, wherein the diversity combiner (70) comprises

15

a branch combining weight controller (73) which receives a respective received sub-carrier signal on each receiving branch for computing combining weight-coefficients and outputting said weight-coefficients, a plurality of multipliers ( $72_1$ ,  $72_2$ ) each connected to a respective metric generator ( $18_1$ ,  $18_2$ ), a diversity combining adder (71) having inputs connected to the multipliers ( $72_1$ ,  $72_2$ ) and an output connected to the transmitted symbol estimation part (40).

20

17. The receiver of anyone of the claims 1 to 16, wherein the transmitted symbol estimation part (40) of each interference canceller is adapted to output information data of the desired signal and the interference signals, thereby forming a multi-user detection receiver.

25

18. A digital multi-carrier communication system comprising a plurality of transmitters and a plurality of receivers (8) according to anyone of the claims 1 to 17.

30

19. A method for canceling interference signals in a multi-carrier signal arrived at a receiver of anyone of the claims 1 to 17, said method comprising the steps:
- a) Receiving a serial baseband multi-carrier signal  
5 containing desired and interference signals over at least one receiving branch;
  - b) converting the received multi-carrier signal into a plurality of baseband sub-carrier signals;
  - c) canceling of co-channel interference in each sub-carrier signal,  
10
  - d) converting the sub-carrier signals to a multi-carrier output signal comprising the desired signal.
20. The method of claim 19 wherein for each sub-carrier  
15 signal the canceling step c) comprises the further steps:
- a) generating sequentially a plurality of sets of desired signal symbol sequence candidates and interference signal symbol sequence candidates;
  - b) generating metric values from a respective received  
20 sub-carrier signal and said plurality of sets of desired and interference signal symbol candidates;
  - c) performing a maximum likelihood estimation by using the metric values in order to determine the most likely set of desired and interference symbol  
25 candidates as the set of the desired and interference signal symbols to be transmitted; and
  - d) outputting bit streams which correspond to said determined set of the desired and interference signal symbols.
- 30
21. The method of claim 20, wherein the step of generating metric values further comprises the steps:

- a) providing transmission channel parameters both of the desired and interference signals;
- b) generating a replica signal of the respective received sub-carrier signal from said plurality of sets of desired and interference signal symbol candidates and said transmission channel parameters,
- 5 c) calculating an estimation error signal from said received sub-carrier signal and said replica signal of said received sub-carrier signal;
- 10 d) computing metric values from said estimation error signal;
- e) determining the most likely set of desired and interference symbol candidates as the set of desired and interference symbols to be transmitted by
- 15 comparing a plurality of calculated metric values which correspond to each set of desired and interference signal symbol candidates;
- f) estimating and/or updating said transmission channel parameters both of desired and interference signal by
- 20 using said determined set of desired and interference signal symbols and said estimation error signal.

22. The method of claim 21, wherein the step of generating a replica signal of the respective received sub-carrier signal further comprises the steps:
- 25 a) providing transmission channel parameters of the desired signal and of the interference signals;
  - b) generating a replica signal of the desired signal;
  - c) generating a replica signal of each interference
  - 30 signal;

- d) combining said replica signal of said desired signal and said replica signal of each interference signal.

23. The method of the claim 20 or 22, wherein the step 20.a) further comprises the steps:

- a) storing pre-known bit sequences as training bit sequences, for the desired signal and for at least one interference signal;

- b) performing a training mode which comprises the steps:

- i) generating said desired signal complex modulation symbols which correspond to the set of training sequences,

- ii) generating said interference signals complex modulation symbols which correspond to the set of training sequences;

- iii) multiplying said desired signal complex modulation symbols with said desired signal transmission channel parameters to obtain a desired signal replica,

- iv) multiplying said interference signal complex modulation symbols with the respective interference signal transmission channel parameters to obtain respective interference signal replicas;

- v) combining said desired signal replica and said interference signal replicas to obtain a replica signal for each received sub-carrier signal;

- vi) subtracting said replica signal of the respective received sub-carrier signal from the respective received sub-carrier signal to obtain an error signal; and

- vii) recursively updating said desired and interference signal transmission channel parameters by using said error signal and said desired and interference signal complex modulation symbols and providing renewed desired and interference signal transmission channel parameters;
- viii) recursively repeating the steps i) to vii) during the training mode;
- c) performing a tracking and information decoding mode which comprises the steps:
  - i) sequentially generating a plurality of bit sets of desired and interference signal candidates as the basis of a maximum likelihood estimation;
  - ii) generating complex modulation symbols according to a plurality of said sets of desired and interference signals;
  - iii) multiplying said desired signal complex modulation symbols by said desired signal transmission channel parameters;
  - iv) multiplying said interference signal complex modulation symbols with said interference signal transmission channel parameters;
  - v) combining the results of steps iii) and iv) to form a replica of a respective received sub-carrier signal;
  - vi) subtracting said replica of received signal from the respective received sub-carrier signal to form estimation error signals;
  - vii) computing absolute-squared values of said estimation error signals as said metric values;



viii) determining the most likely bit set of desired and interference signal candidates as the bit set of desired and interference signal to be transmitted by comparing a plurality of said metric values on the basis of a maximum likelihood estimation;

ix) generating the set of desired and interference signal complex modulation symbols according to said determined bit set of desired and interference signal;

x) estimating and/ or recursively updating said transmission channel parameters of desired and interference signals by using said determined set of desired and interference signal complex modulation symbols and said estimation error signal which corresponds to said determined set of desired and interference signal complex modulation symbols; and

xi) recursively repeating the steps i) to x) during the information data decoding mode.

24. The method of claim 23, wherein step b) is replaced by the following steps:

a) generating said desired signal complex modulation symbols which correspond to the set of training sequences;

b) generating said interference signals complex modulation symbols which correspond to the set of training sequences,

c) estimating desired and interference signal transmission channel parameters by calculating cross-correlation between the respective sub-carrier signal

and said complex modulation symbol sequences of said desired and interference signals.

25. The method of anyone of the claims 19 to 24 comprising  
5 the steps:
- a) receiving said serial baseband multi-carrier signal over a plurality of diversity receiving branches;
  - b) converting each serial baseband multi-carrier signal into a plurality of baseband sub-carrier signals;
  - 10 c) diversity combining respective sub-carrier signals of each diversity receiving branches and canceling of co-channel interference in the diversity combined sub-carrier-signals.
- 15 26. The method of claim 25, wherein step 20.b) comprises the steps:
- seperately generating metric values from each respective received sub-carrier signal to be diversity combined and said plurality of sets of desired and interference signal  
20 symbol candidates and
- diversity combining the seperately generated metric values.

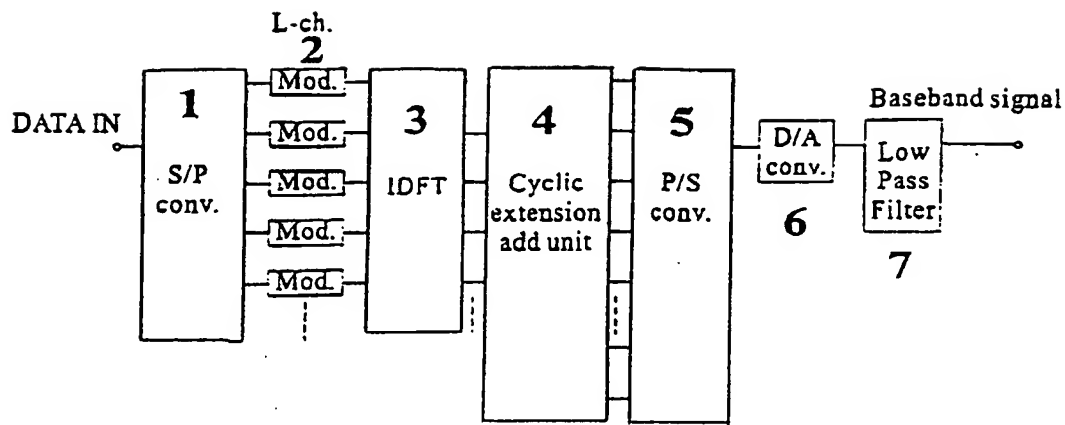


Fig. 1A  
PRIOR ART

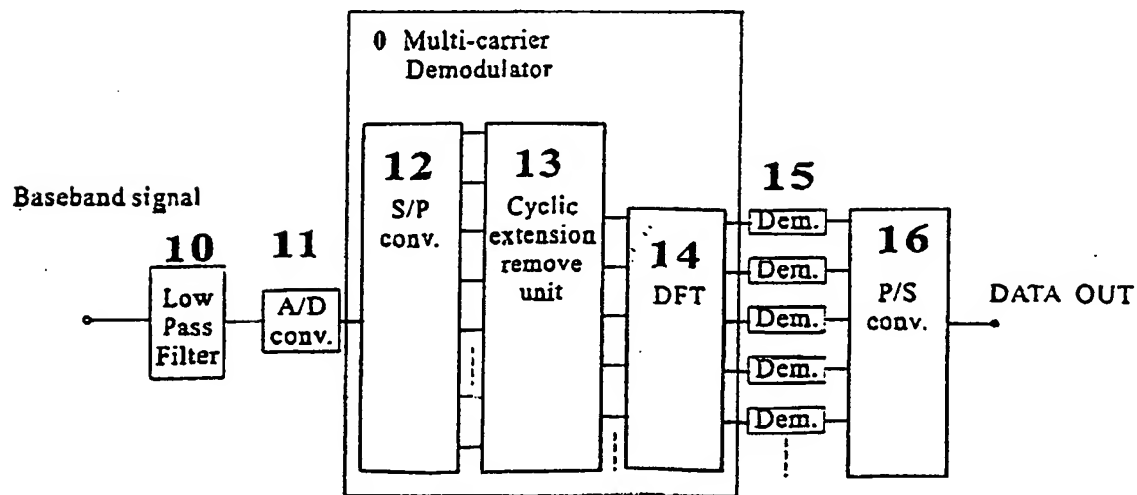


Fig. 1B  
PRIOR ART

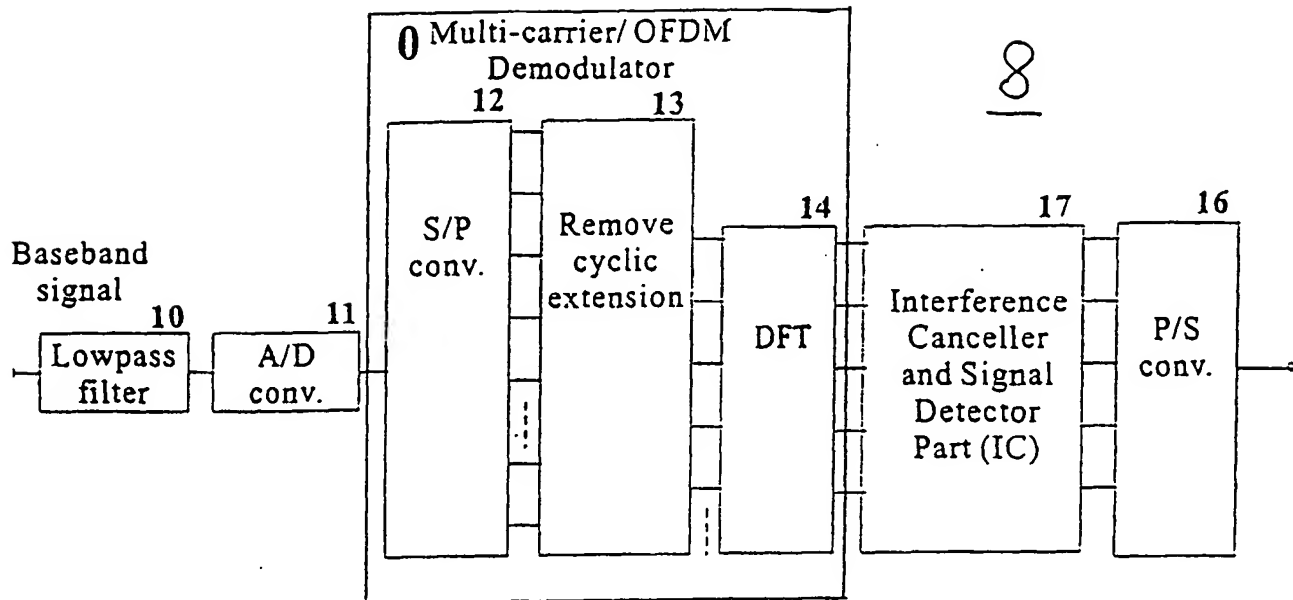


FIG. 2A

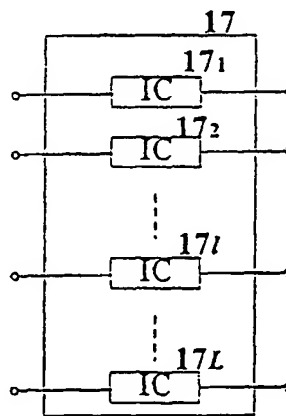


FIG. 2B

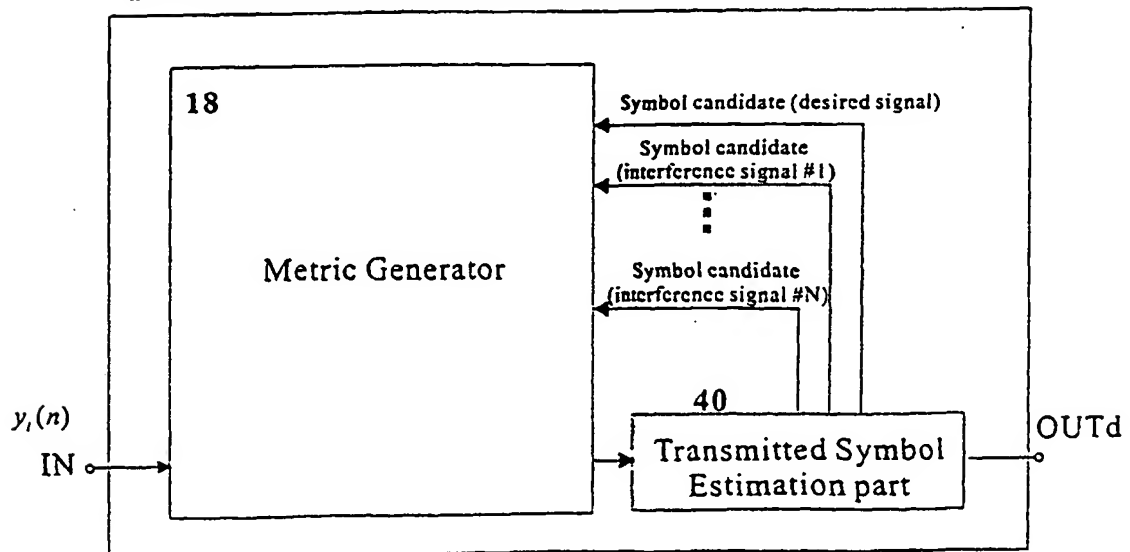
17<sub>l</sub> Interference Canceller for the *l*-th sub-carrier

FIG. 2C

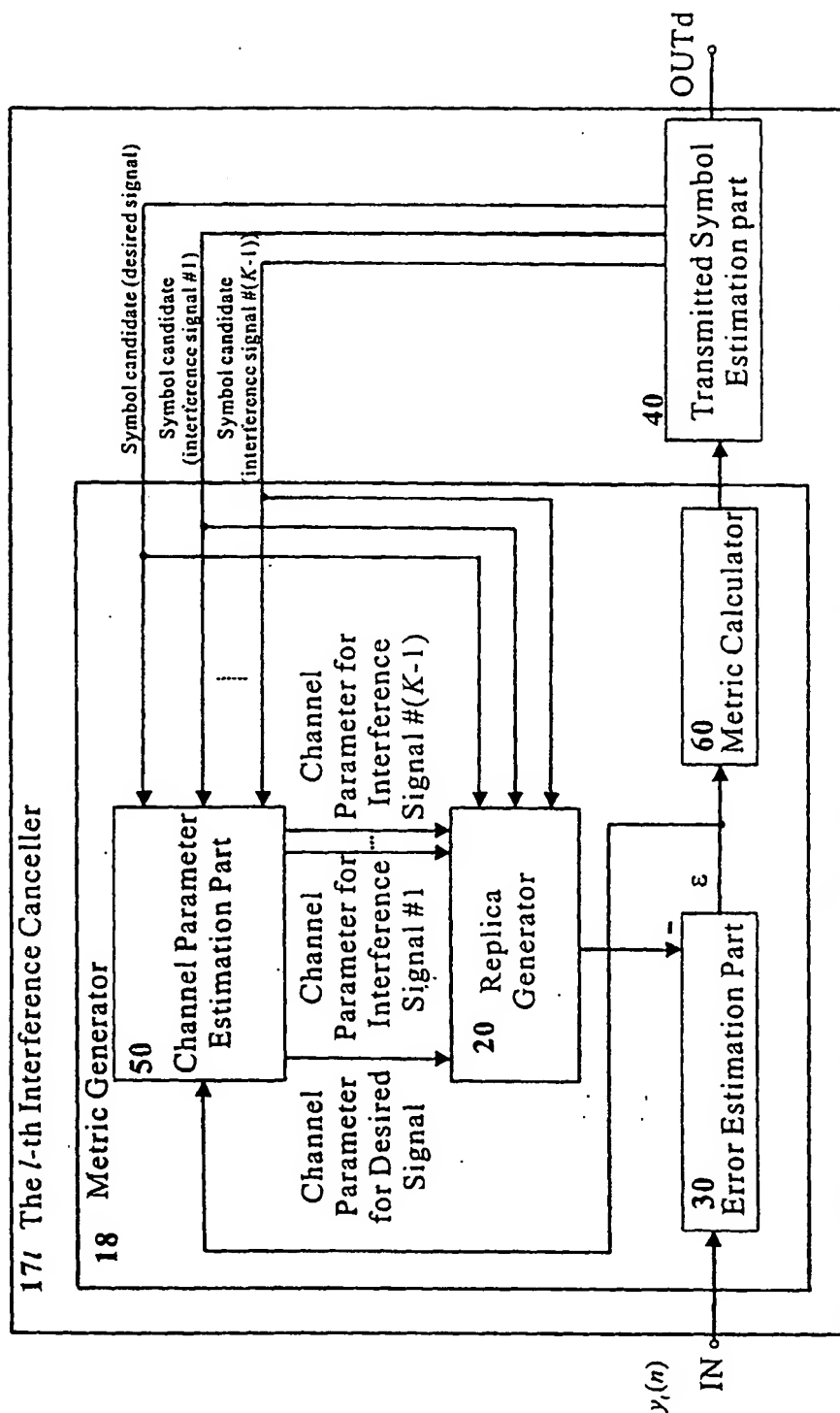


FIG. 3

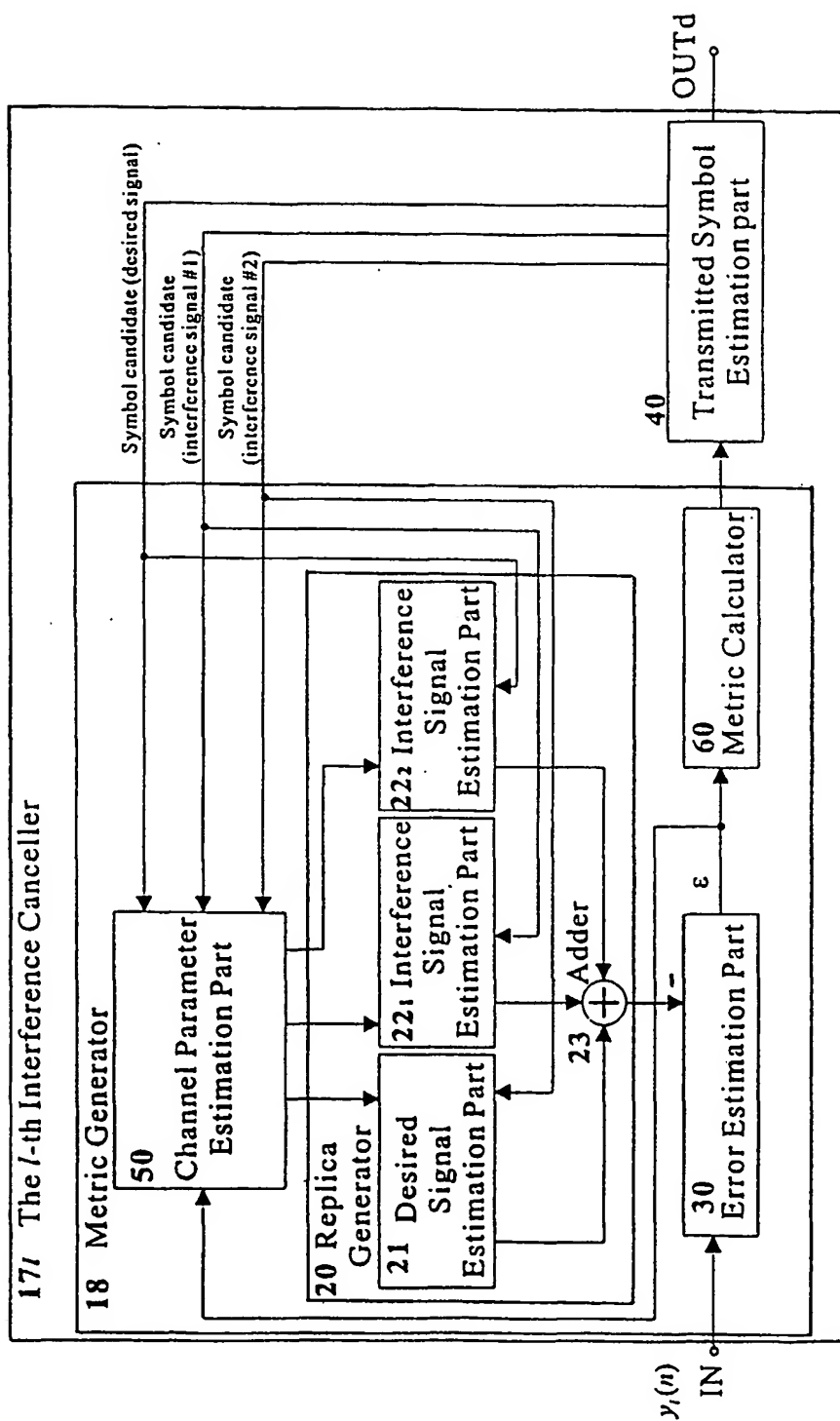


FIG. 4

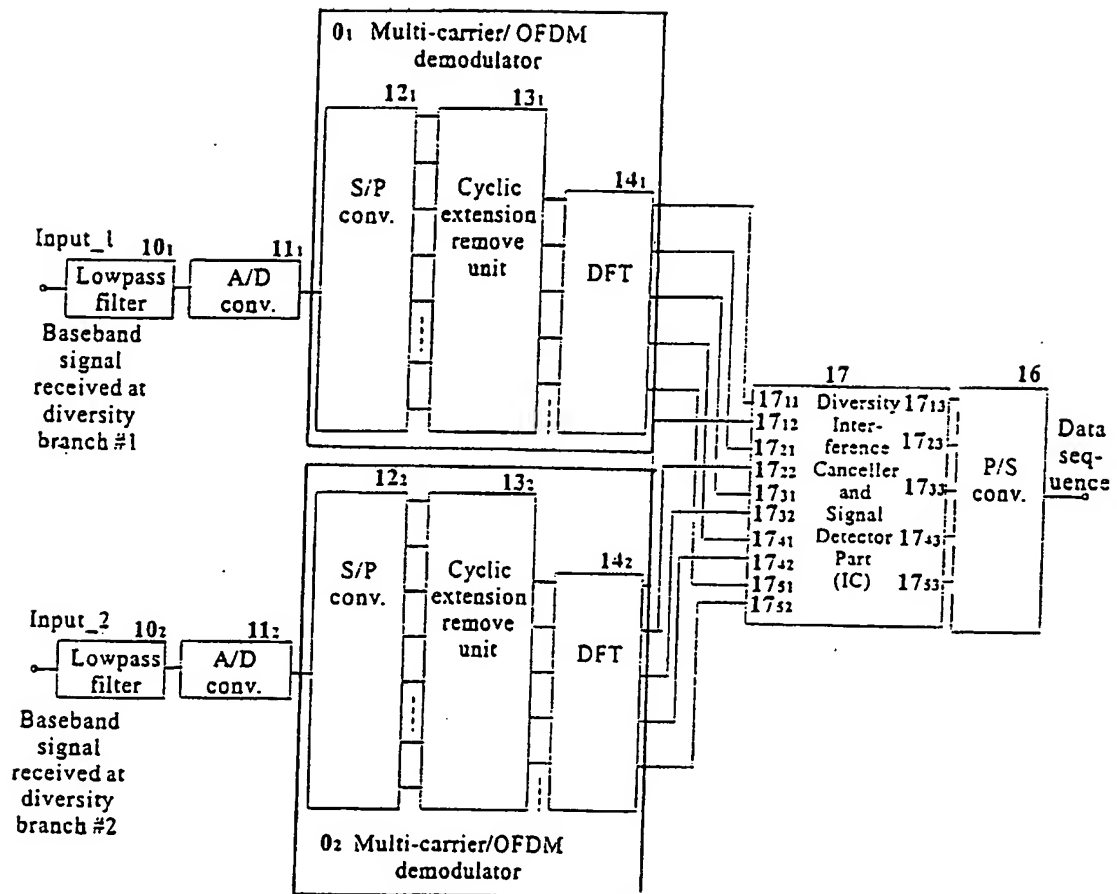


FIG. 5A

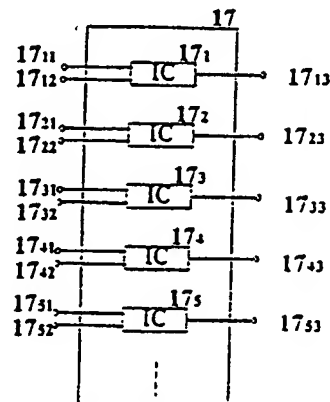


FIG. 5B

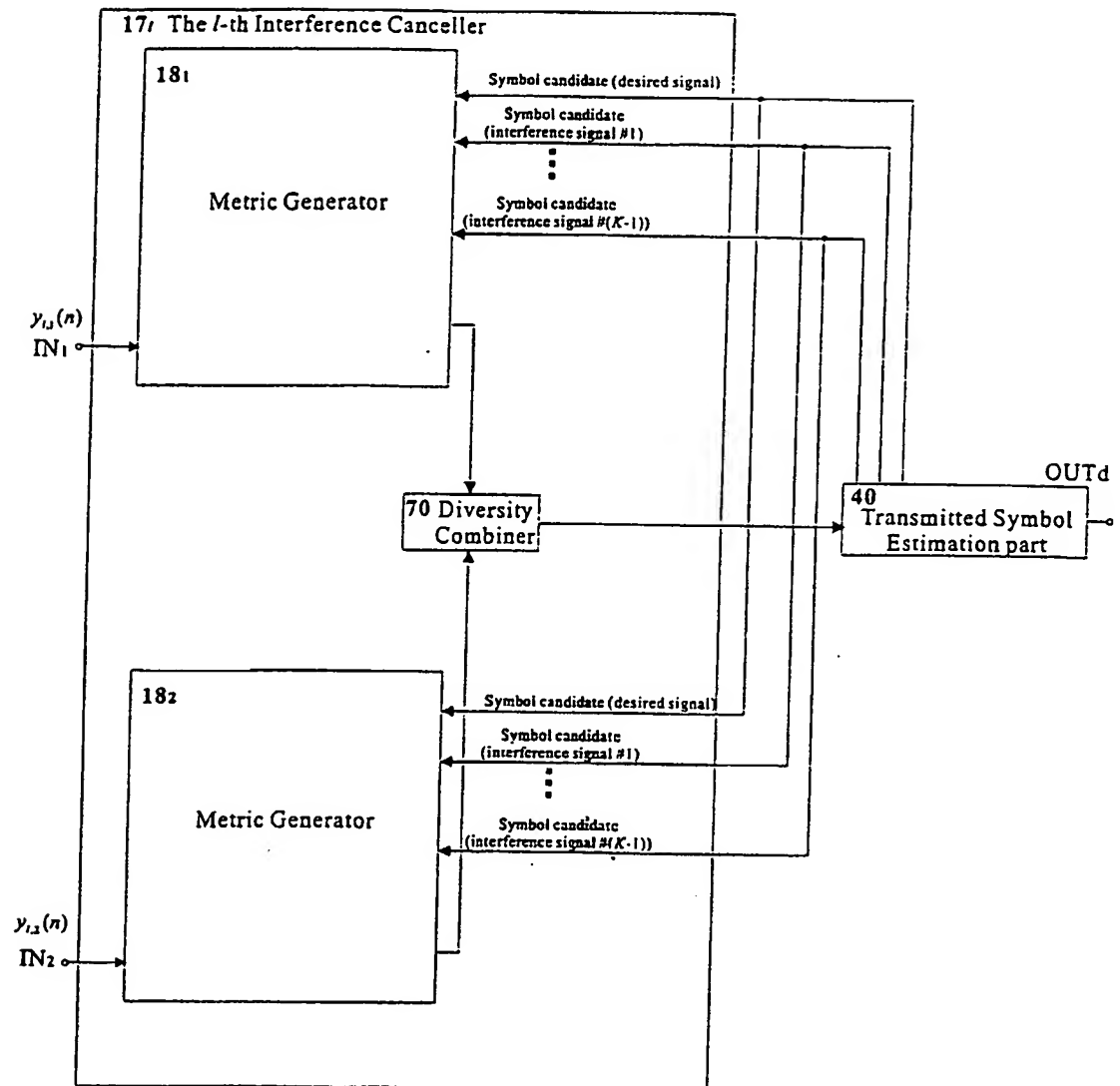


FIG. 5C



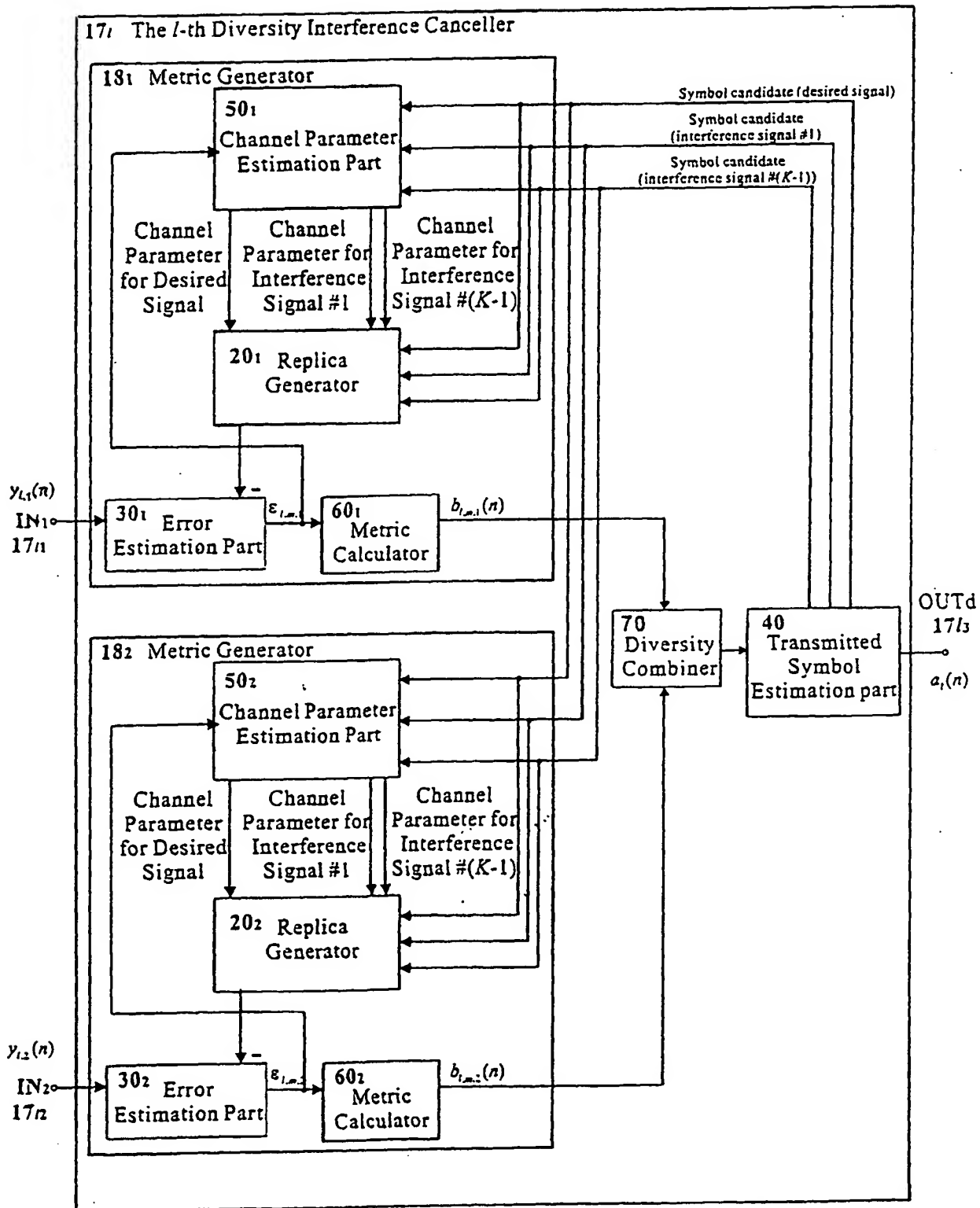


FIG. 6

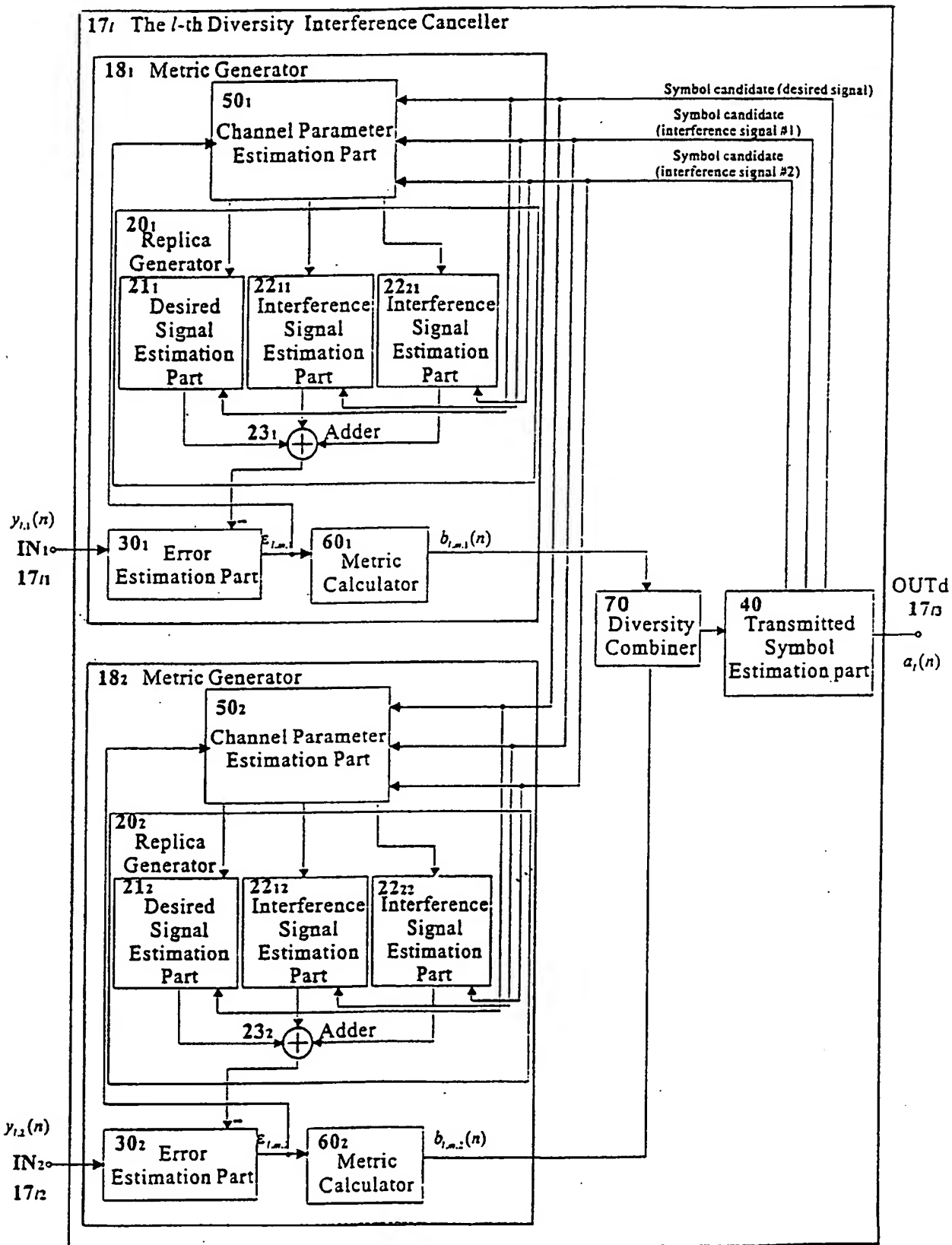


FIG. 7

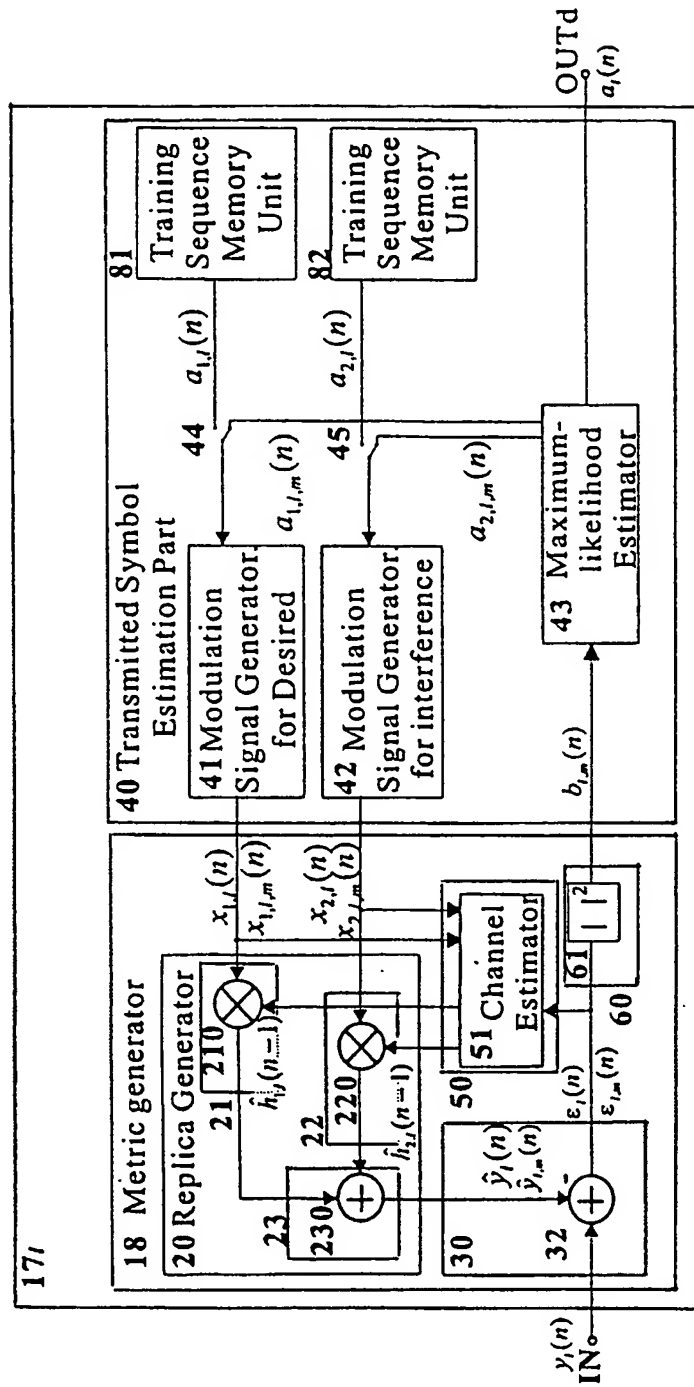


FIG. 8

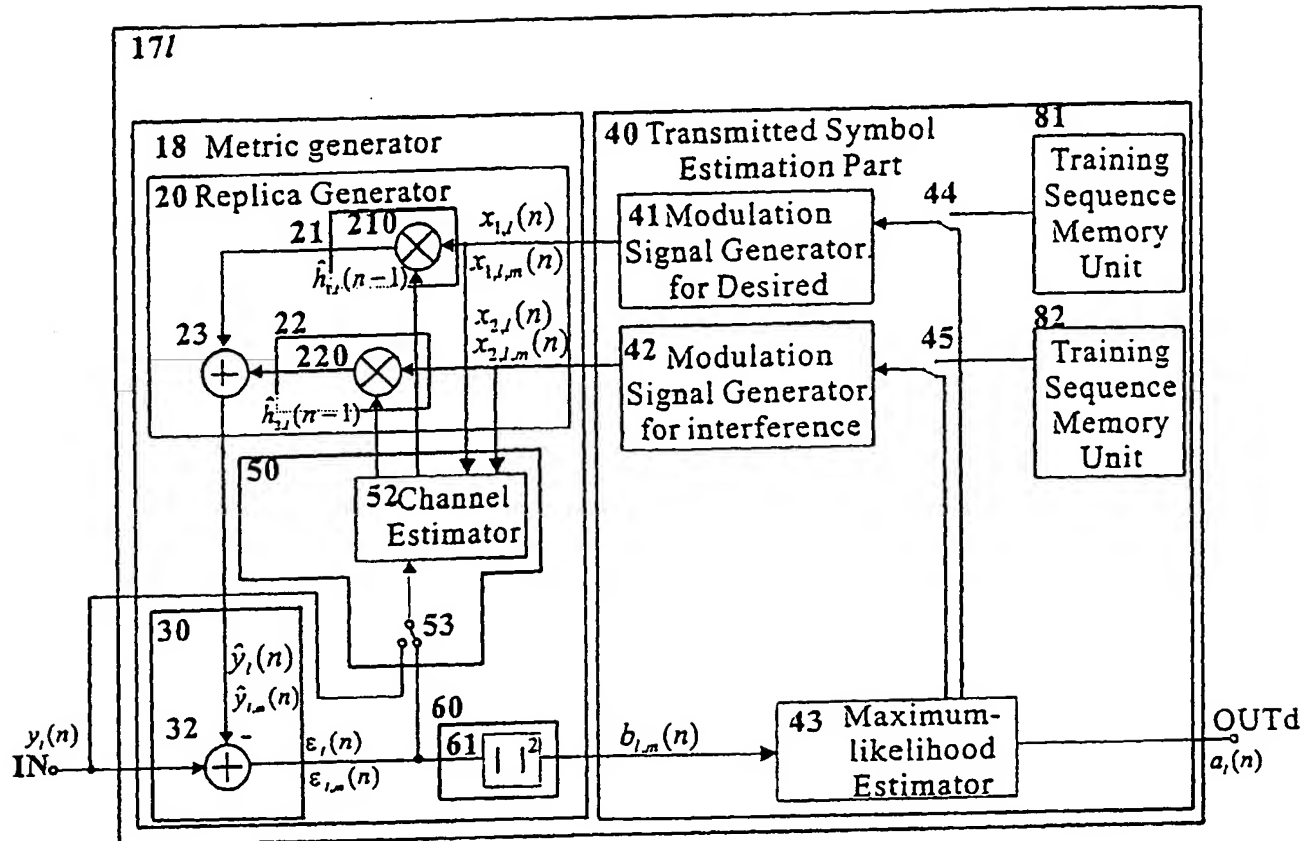


FIG. 9

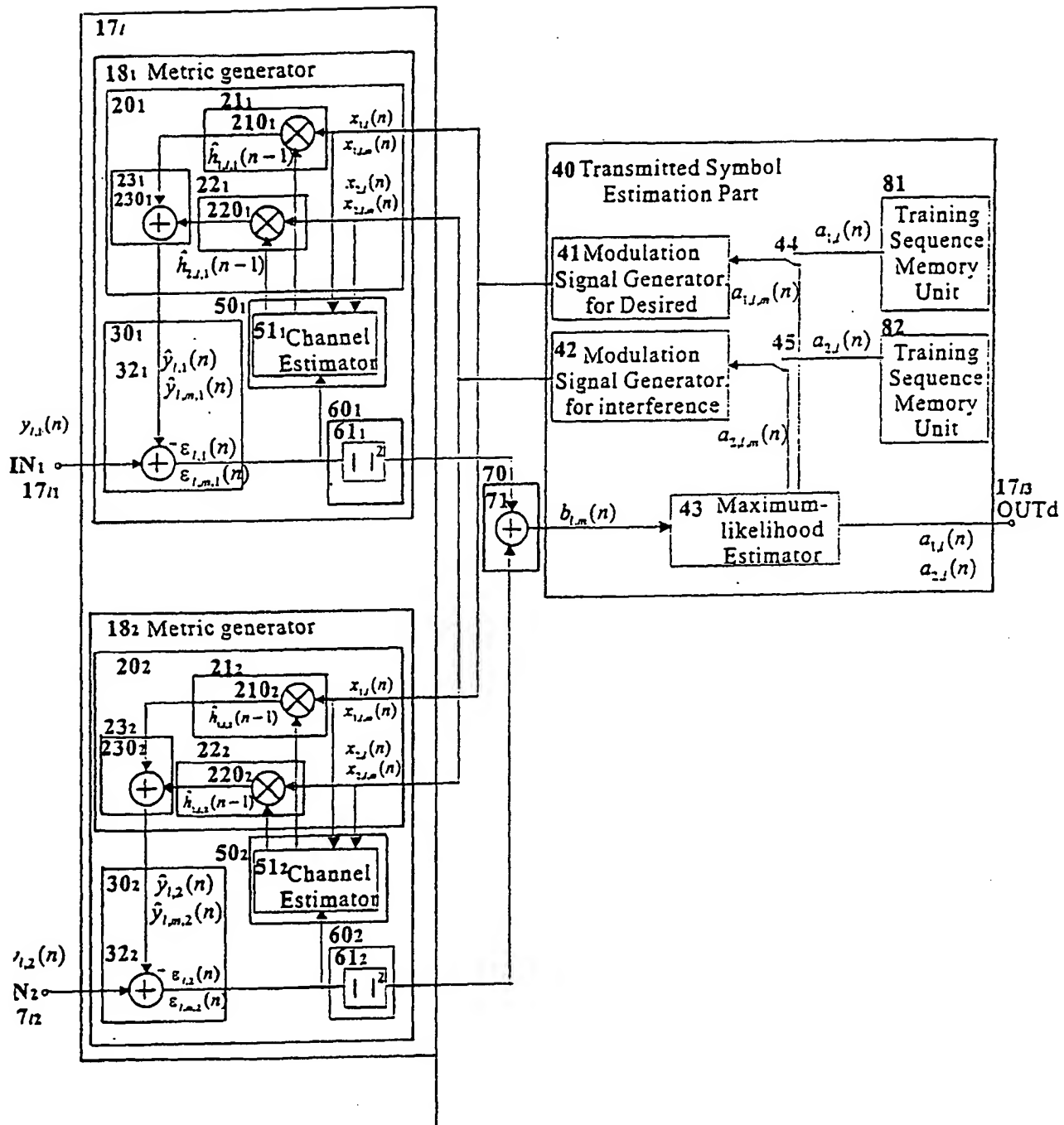


FIG. 10

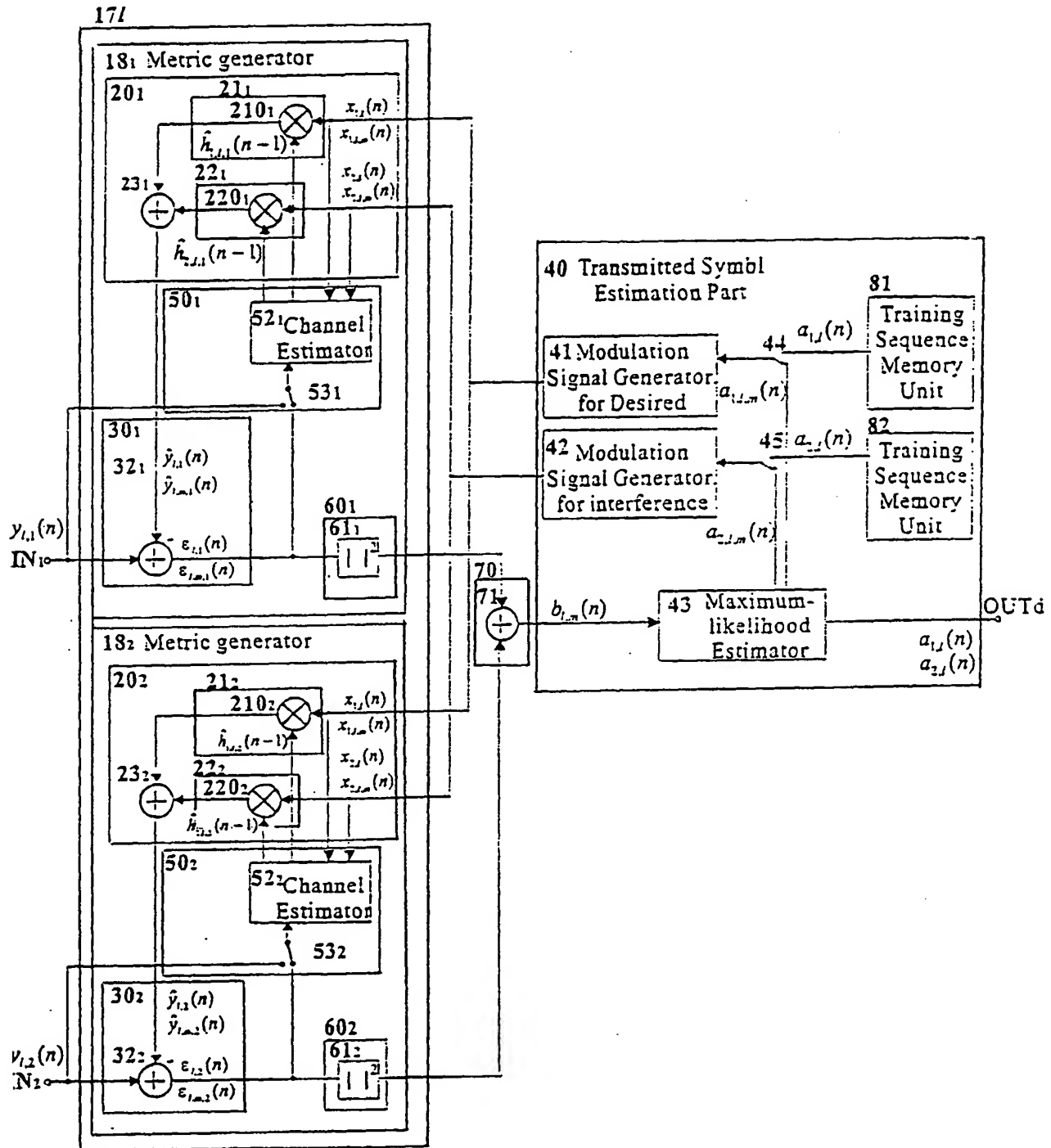


FIG. 11

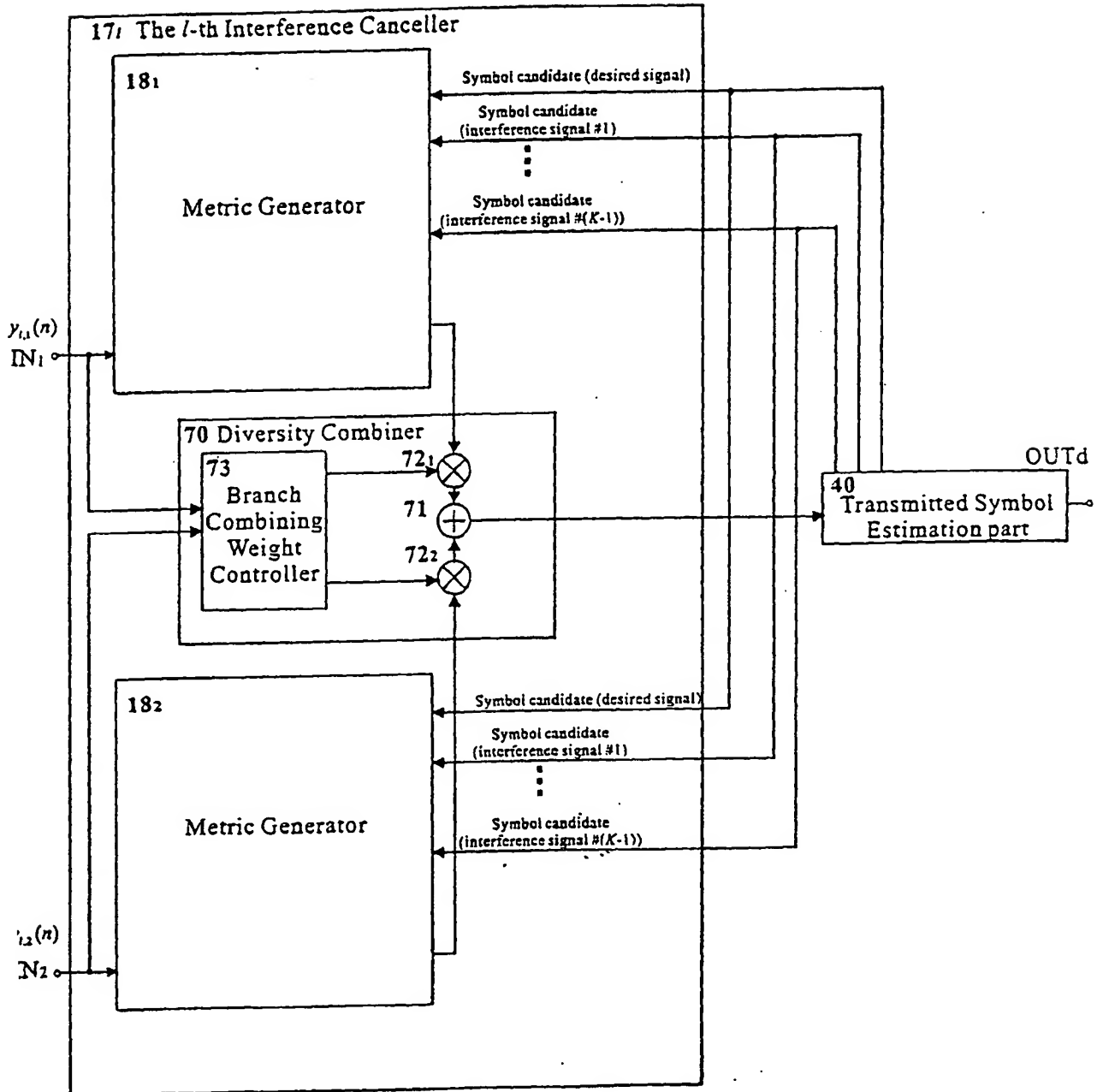


FIG. 12

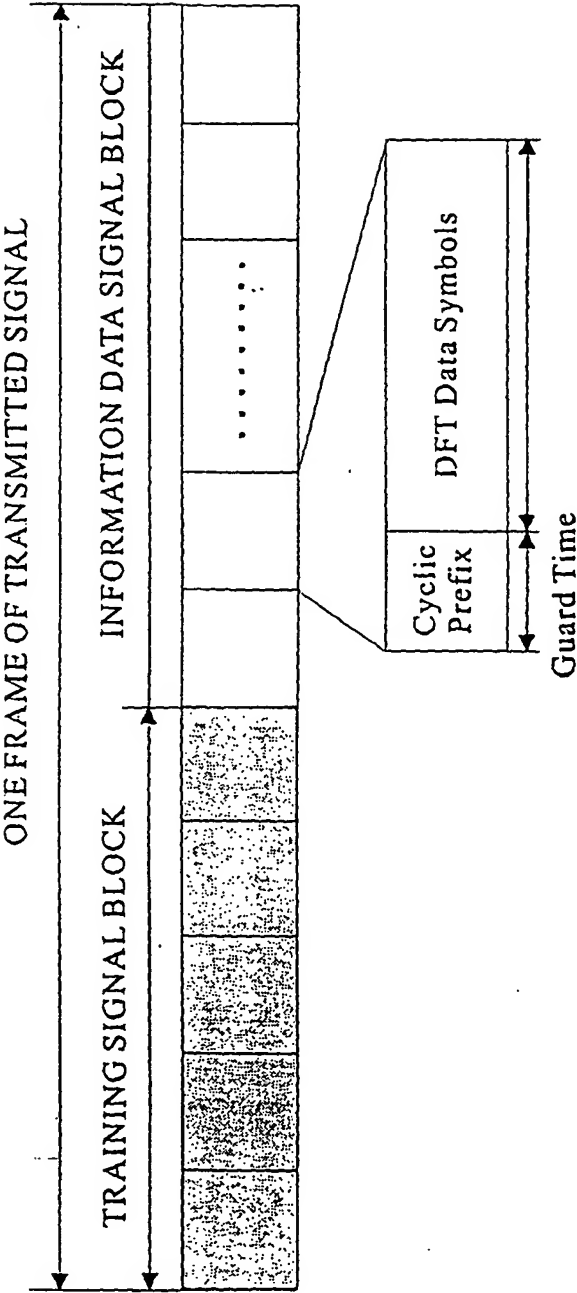


FIG. 13



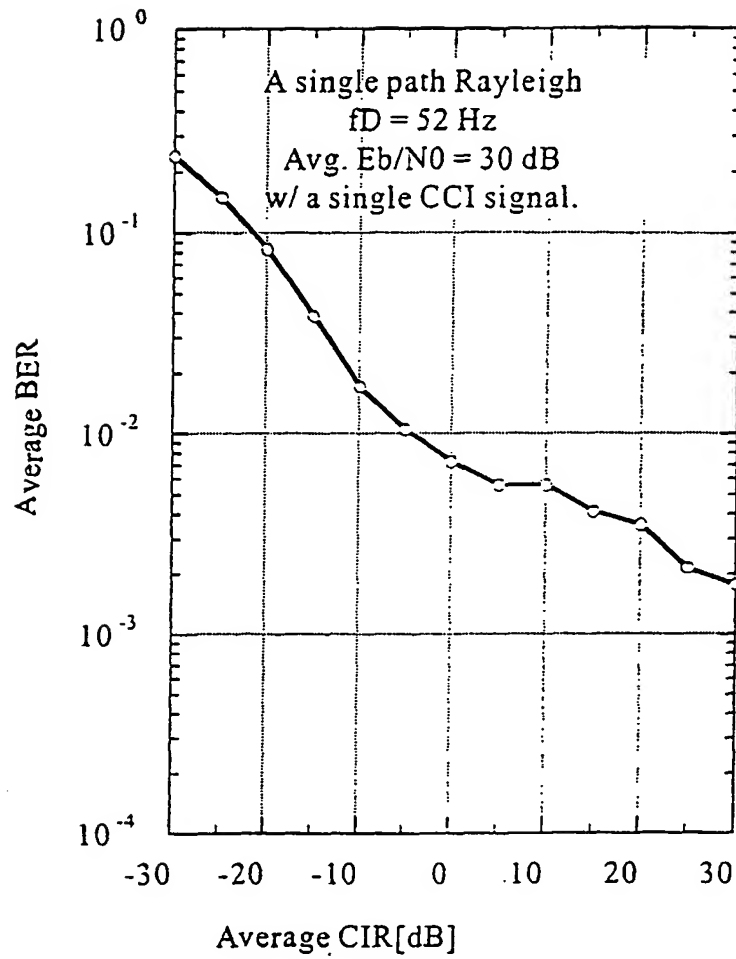


FIG. 14

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC 7 H04L27/26 H04L25/03 H04B7/08 H04L1/06

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04L H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 867 478 A (BAUM KEVIN LYNN ET AL) 2 February 1999 (1999-02-02) column 1, line 21 - line 41 column 3, line 15 - line 26 column 4, line 13 - column 5, line 59 column 12, line 15 - column 13, line 6 column 15, line 1 - line 65 column 17, line 8 - line 23 column 18, line 1 - line 8 column 23, line 64 - column 27, line 41; figures 15-19 column 28, line 21 - line 37; figure 22 --- -/--	1-26

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

## \* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"Z" document member of the same patent family

Date of the actual completion of the international search

28 July 2000

Date of mailing of the international search report

09/08/2000

Name and mailing address of the ISA

 European Patent Office, P.B. 5818 Patentlaan 2  
 NL - 2280 HV Rijswijk  
 Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
 Fax: (+31-70) 340-3018

Authorized officer

Koukourlis, S

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>US 5 537 443 A (YOSHINO HITOSHI ET AL)  16 July 1996 (1996-07-16)  cited in the application  abstract  column 7, line 9 - line 40  column 9, line 29 -column 10, line 62  column 22, line 32 -column 25, line 32  figures 3,4,15  claims</p>	1-26
A	<p>US 5 973 642 A (SOLLENBERGER NELSON RAY  ET AL) 26 October 1999 (1999-10-26)  claims</p>	1-26
A	<p>MUNSTER M ET AL: "Co-channel interference  suppression assisted adaptive OFDM in  interference limited environments"  IEEE VTS 50TH VEHICULAR TECHNOLOGY  CONFERENCE,  19 - 22 September 1999, pages 284-288  vol.1, XP002143788  Piscataway, NJ, USA  ISBN: 0-7803-5435-4  the whole document</p>	1-26

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5867478 A	02-02-1999	EP 0983654 A WO 9859450 A	08-03-2000 30-12-1998
US 5537443 A	16-07-1996	EP 0637139 A WO 9417600 A JP 2678823 B	01-02-1995 04-08-1994 19-11-1997
US 5973642 A	26-10-1999	NONE	